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THE DAISY DECELERATOR

Richard F. Chandler

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6571st Aeromedical Research Laboratory
Aerospace Medical Division
Air Force Systems Command
Holloman Air Force Base, New Mexico

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FOREWORD

Acknowledgement is given to the Land-Air Aeromed Support Group, Division of Dynalectron Corp., who, as operating contractor for the Daisy Decelerator, have done so much to contribute to the successful completion of many projects on that facility, and to the numerous military and civilian Air Force personnel who have contributed to the design, construction and operational usefulness of the facility.

This technical report has been reviewed and is approved for publication.

C. H. Kratochvil

C. H. KRATOCHVIL, Lt Colonel, USAF, MC
Commander

ABSTRACT

The Daisy Decelerator is a sled-track facility used for biodynamic and equipment impact testing at the 6571st Aeromedical Research Laboratory at Holloman AFB, New Mexico. Since its first operational use in 1955, it has been developed to produce an impact force capability of up to 200,000 lbs (equivalent to 200 G for 1000 lb total weight), a maximum impact velocity of 175 ft/sec, and a maximum displacement during impact of 4 feet. Test sleds are available to carry one to three 250 lb test subjects in a variety of orientations relative to the impact force vector. These sleds are capable of accepting other payloads through simple adaptors.

Propulsion of the sled is provided by a pneumatic piston device which accelerates the sled to the desired velocity over a distance of 42 feet. The sled is then released to coast into a waterbrake located further down the track. The waterbrake acts on the sled to provide the required impact test pulse. The waterbrake force is controlled by pre-set orifices and can provide a variety of test pulse shapes limited only by the mechanical characteristics of the system. Tests have demonstrated velocity reproduced with a standard deviation of 1.6%, and deceleration reproduced with a standard deviation of 3.5%.

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INTRODUCTION

The Daisy Decelerator, Figures 1 and 2, is a deceleration test device capable of producing deceleration pulses up to 200 G over a maximum of 4 foot displacement to human, animal and equipment test items. The device consists of a test sled which slides along two horizontal rails, an accelerating device and a hydraulic brake. The sled is propelled by a pneumatically powered piston accelerator (the air gun), and is stopped by a hydraulic brake of unique design which produces a controlled deceleration pulse.

Historical Development

The design of the Daisy Decelerator was initiated on May 23, 1953, when the Aeromedical Field Laboratory established the test requirements for this facility. The initial design of the 120-foot track, sled and brake was done at the Engineering Laboratory then at Holloman, and the device was first used in 1955. Construction was done under separate contract for each item (1, 2, 3), and acceptance testing was begun in the summer of 1955. Although the use of an air gun for propulsion was originally contemplated for the facility, these first tests used ejection seat catapults to provide the force necessary to bring the sled to the required impact velocity. Mission and organizational changes (4) eliminated the Engineering Laboratory as a service organization to the Aeromedical Field Laboratory, and prevented completion of the air gun design. Catapults continued to be used for propulsion until acceptance of the air gun during August 1960. The first human test was made February 17, 1956, the first animal test on November 16, 1955, and the first equipment test on September 22, 1955 (5).

The sled used in these tests was merely a flat topped test vehicle, with limited versatility regarding test item placement. Although small animals and equipment items could be adapted easily to the sled in a variety of positions, it was necessary for the test subjects to lie down, either on their back or on their side, to distribute the inertial load at impact over the sled structure (6, 7, 8,

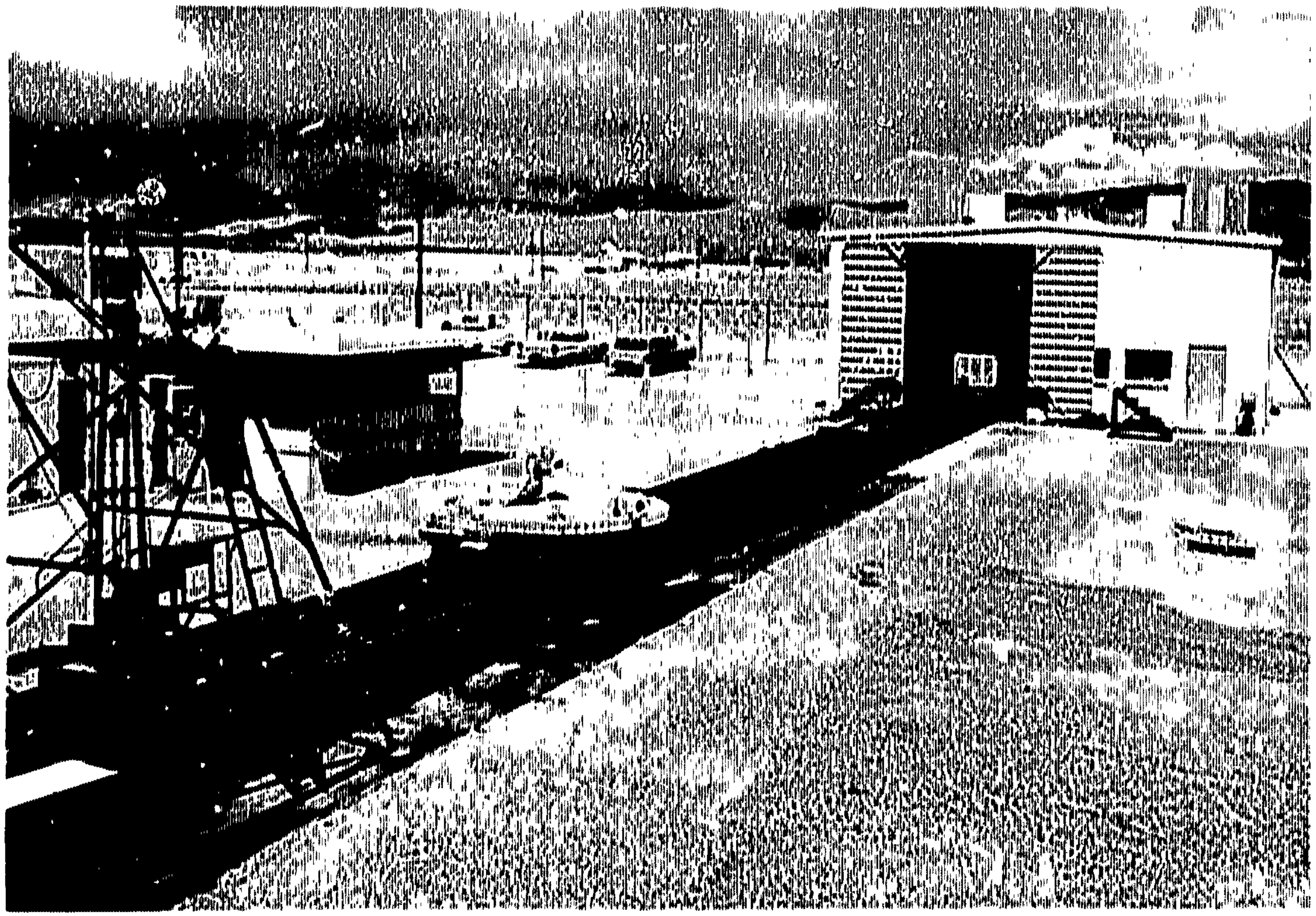


Figure 1. The Daisy Decelerator. This view shows the facility from the midpoint of the track towards the breech end. The airgun accelerator is housed in the building to the right. The track continues left, out of the picture, for about 120 feet. The tower in the left of the picture provides a firm stand for high-speed overhead cameras, and is located over the waterbrake, here mounted at the track midpoint. Instrumentation and fire control buildings are in the left background.

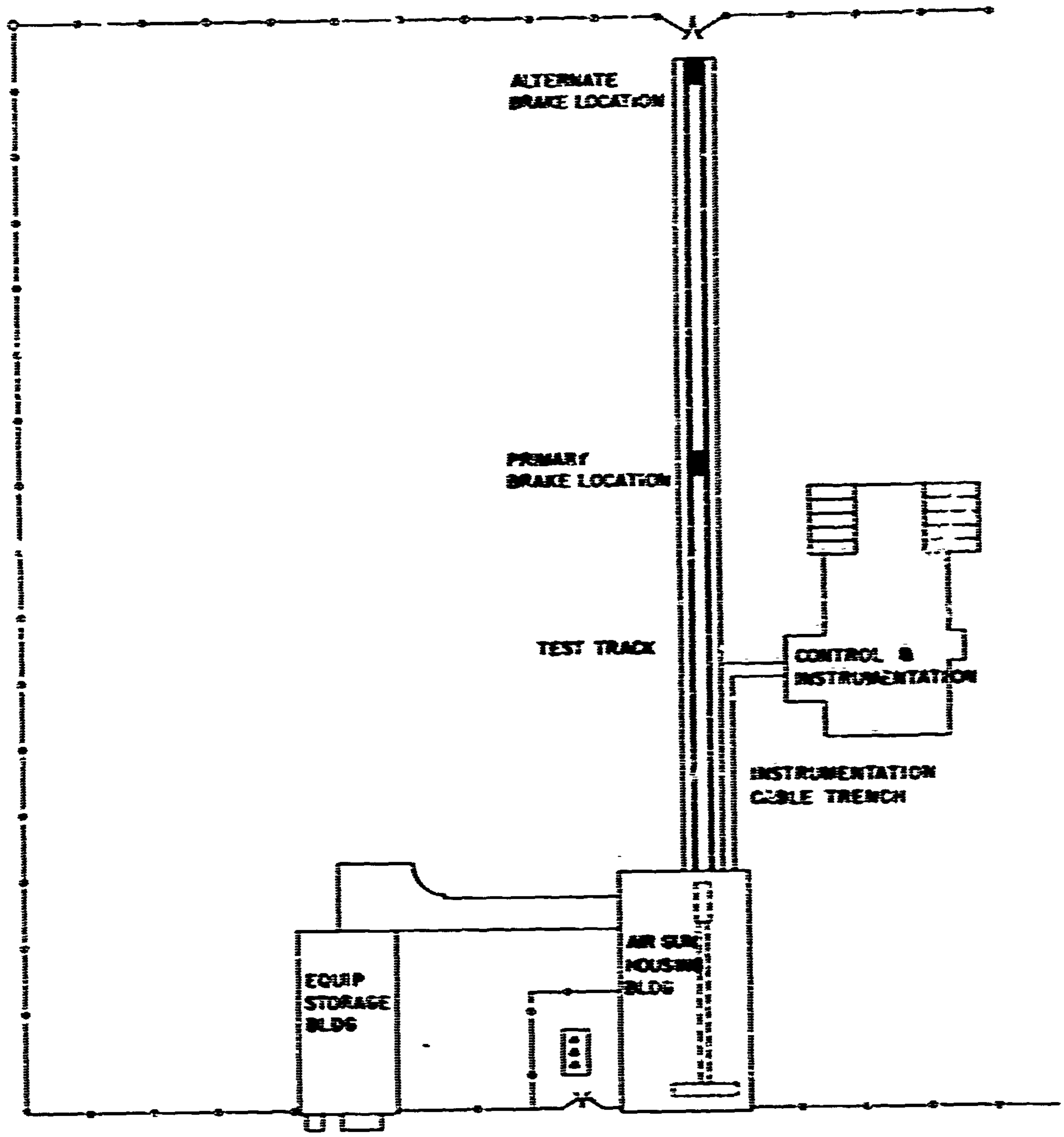


Figure 2. Daisy Decelerator Site Location in the Building 1200 Area at Holloman AFB. Relative positions of test track, support buildings and brake locations are shown.

9, 10), Figure 3. This was undesirable from both psychological and physiological considerations; consequently, a contract was awarded for the design and fabrication of a sled which would permit these larger subjects to be seated in a conventional position (11, 12, 13, 14, 15, 16, 17), Figure 4. This sled was used for much of the testing during the early phase of facility development, and proved to be so useful that two additional sleds of similar design were obtained (18, 19).

Experience with this sled showed that the continued use of ejection seat catapults for sled propulsion was not feasible. The heavier weight of the second sled limited the velocity which could be obtained and so greatly exceeded the design limitations of the catapult that catapult case failures became common. Moreover, the reproducibility of the impact velocity was less than desired for human impact research. The impact velocity could be changed only by changing the launch position of the sled toward or away from the brake, thus altering the coasting distance and hence the velocity lost during the coasting distance. This presented operational problems because of the difficulties encountered in relocating the launch position.

To lessen some of these problems, attempts were made to use two catapults firing simultaneously and to use more powerful catapults. These attempts were of limited success because of the difficulty of achieving simultaneous firing of both catapults. More important, the acceleration (because of the short stroke length available) produced by these catapults in obtaining the desired velocity became so great as to constitute a possible cause of artifact in the data gathered during the impact phase of the test. It was apparent that the airgun, originally a part of the facility conceptual design, was needed.

The airgun was designed and fabricated under a contract awarded January 3, 1958 (20). After some difficulty in the initial testing, and subsequent repair, the airgun was accepted for operational use during August 1960 (21). The airgun greatly

Figure 3. Sled Number 1 with Volunteer Test Subject. Direction of motion is from left to right. Note that the subject was required to lie on his side when this sled was used.

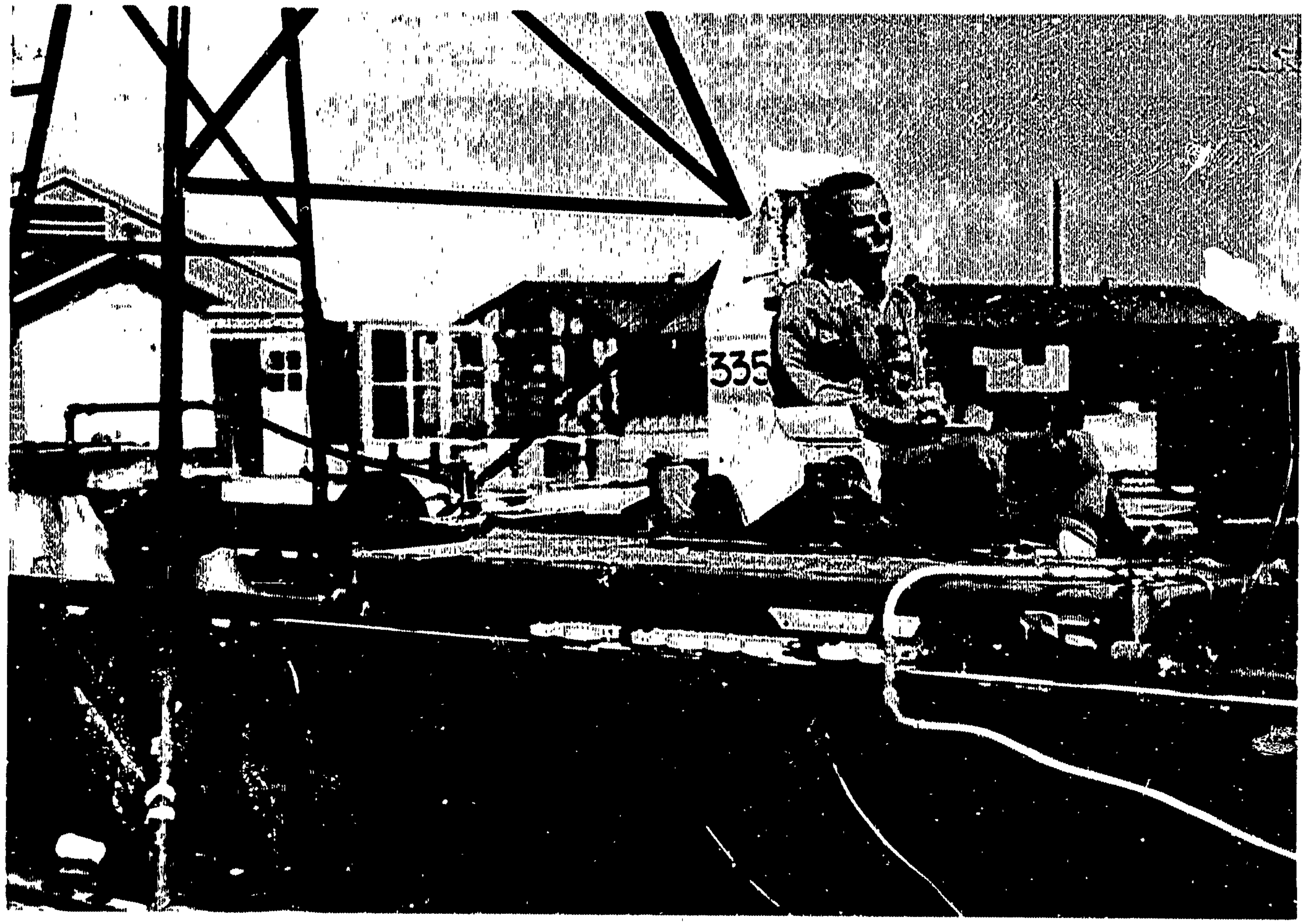


Figure 4. Sled Number 3 with Subject in a Conventional Position. This sled is typical of sleds No. 3 and 5. The subject can be seated upright, forwards or backwards, at various pitch angles. This picture shows the sled during impact. The subject for this test, Major Eli L. Beeding, Jr., sustained an impact of over 40 G.

increased the velocity range available for testing as well as eliminated those problems associated with the use of the ejection seat catapults. It did, however, create a previously unanticipated problem.

In human and animal testing on this facility, it is necessary to provide time between the acceleration and impact phases of the test to assure that the test subject is in the proper position for the impact, and that the effects of the acceleration (however small) do not invalidate the impact response data. At the high velocities available with the airgun, the length of track available did not permit long enough coast times to meet this requirement.

Consequently, in February 1961, a contract was awarded to extend the length of the track (22). This extension was accepted for operational use during October 1962. For convenience, this extension is used only when required, the original length of track sufficing for the majority of test requirements.

The sleds available for use at that time were adequate for testing human sized payloads at high impact levels, but were limited in that the orientation of the impact force vector in regard to the subject could be changed only in pitch (rotation about the Y axis). Developments in aircraft and spacecraft required additional data in other impact orientations. To permit the collection of these data a new sled was needed which would provide a wider range of orientations. A contract was awarded on January 30, 1961 to design and fabricate such an "omnidirectional" sled (23). This sled was to accept the standard seated subject and permit the seat to be oriented independently in 10° increments of roll, pitch and yaw. The design and fabrication of this sled, within the weight limitations, to meet the design goals proved to be a formidable task. After many difficulties, the contract effort was ended and the existing components were brought back to Holloman AFB. The remainder of the work on this sled was accomplished as a joint effort by the Aeromedical Laboratory and the Field Maintenance fabrication shops at Holloman AFB. The sled was finally completed in August 1962, just in time to be used for a spacecraft research effort to establish acceptable operational levels for recovery impact (24, 25, 26).

The success of this research effort led to a desire to investigate various prototype crew seating and restraint systems to be used in the Apollo spacecraft. A first attempt to adapt an existing sled to test a 3-man couch system met with limited success because of differences between the sled-couch attachment point and the sled-space capsule attachment point locations (27, 28). A completely new sled was needed for this testing, one which would match the capsule attachment points as nearly as possible and yet maintain the versatility necessary to simulate impacts at various orientations. The design of a suitable sled was undertaken as a cooperative effort between the NASA Manned Spacecraft Center and the Aeromedical Research Laboratory and the sled was fabricated by the Holloman AFB Field Maintenance shops. Because of the high center of gravity of this sled, it was necessary to lift the waterbrake so as to align the braking force with the center of mass (to reduce overturning moments during the impact phase of the test). Thus, a spacer was built to go between the waterbrake and the foundation. This system was first tested in October 1966.

The development of the data collection system has been consistent with the development of the test hardware. The first tests were instrumented only with strain gage accelerometers feeding directly into an oscillograph, one lead of electrocardiogram data, and a simple impact velocity measurement. As testing became better defined and the data requirements became more sophisticated, the data collection system was expanded and improved. Physiological measurements can be made on as many as three subjects simultaneously and can include vector cardiograms (or other leads as required), electromyograms, electroencephalograms, respiration rate and depth, automatic blood pressure measurements (either by cuff or implanted transducers), blood flow and even fetal electrocardiogram (29). Accelerations, velocity and strains are measured routinely. Displacements, velocities and accelerations of selected points on the subject can be obtained through the use of photometric techniques.

Onsite data handling and processing techniques permit permanent oscillograph data and high speed film coverage to be reviewed within minutes after a test, so that all data will be avail-

able to the researcher before the subsequent test, even with as many as 8 to 10 tests per day. High speed, multiple exposure X-rays can be made during the impact to determine internal organ positions at any time during the impact. Magnetic tape recording is routinely available to permit automatic machine processing of data or other playback as required. On-board data collection systems have been developed using recorders which can collect data during impacts in excess of 100 G.

As can be seen in the above paragraphs, the Daisy Decelerator impact test facility is a product of several years evolution and development. This development continues. New items of test equipment, new instrumentation and new data collection and processing techniques are constantly under consideration and investigation. No report such as this can adequately describe the facility as it will exist at anytime in the future, especially considering the rapid process being made in instrumentation and analysis techniques. At best, this report will describe only the major facility components and operational characteristics and perhaps indicate the versatility of the facility for both equipment and physiological impact testing.

II

DESCRIPTION OF MAJOR COMPONENTS

A. Track

The track consists of two solid steel rails, three inches in diameter and five feet apart (centerline distance), supported on a welded steel superstructure which is bolted to a reinforced concrete foundation. The rails are cold rolled steel for smooth surface finish and close tolerance and have joints aligned by means of concentric dowel pins. Provision is made for lateral adjustment of rail position by tapered wedges and for vertical adjustment by shims. Alignment of both rails is maintained so as to produce less than 2 G (peak) vibrations on the moving sled in the vertical and lateral directions.

The track is designed to withstand reactions from the sled equivalent to a static vertical load of 40,000 lbs and a lateral load of 10,000 lbs. Midway down the track there is provision for mounting a 200,000 lb force hydraulic brake, and a 400,000 lb force hydraulic brake can be mounted at the muzzle end.

A cross section of the track is shown in Figure 5.

B. Accelerating Device (Airgun) (Figure 6 and Figure 7)

The accelerating device (30), commonly called the airgun, is used to provide the test sled with sufficient velocity to accomplish the required deceleration pattern. The device was designed to accelerate sleds weighing between 250 lbs and 2000 lbs to predetermined velocities between 30 to 175 fps with an onset of acceleration less than 500 G/sec. It has been tested in excess of these limits (Table I). The airgun was designed to provide sled velocities reproducible to within $\pm$ 5%. In actual practice, much better performance is obtained when operating within the design limits (see Section III for test data). Velocities below design specifications tend to have somewhat larger variation. Sleds weighing more than 2000 lbs do not appear to have greater velocity variation than do lighter sleds. Sleds weighing in excess of 5000 lbs can be accelerated to maximum design velocity.

The airgun consists of five main assemblies: thrust piston and housing, waterbrake assembly, onset control mechanism, pneumatic system, and fire control panel. The first four of these are assembled into one unit located at the breech end of the track (Figure 7).

The basic operating principle of the airgun is similar to a large ejection seat catapult, i.e., telescoping tubes are allowed to expand under the action of internal pressure. In addition to size, the major differences between the airgun and an ejection seat catapult are that the pressure source is pneumatic rather than a combustion device, and the thrust tube is stopped by the airgun waterbrake rather than attached to, and thus traveling

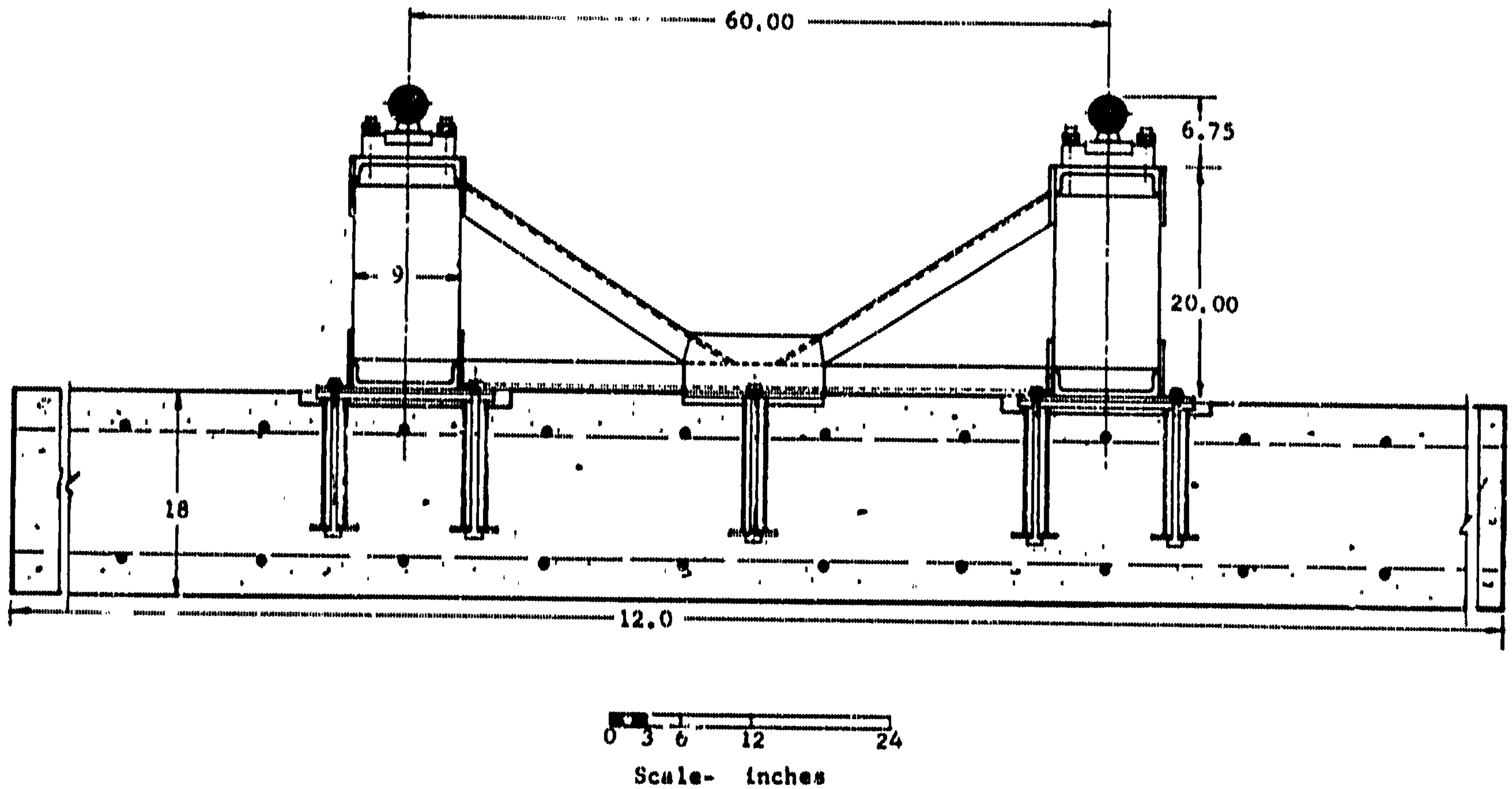


Figure 5. Typical Cross Section - Daisy Decelerator

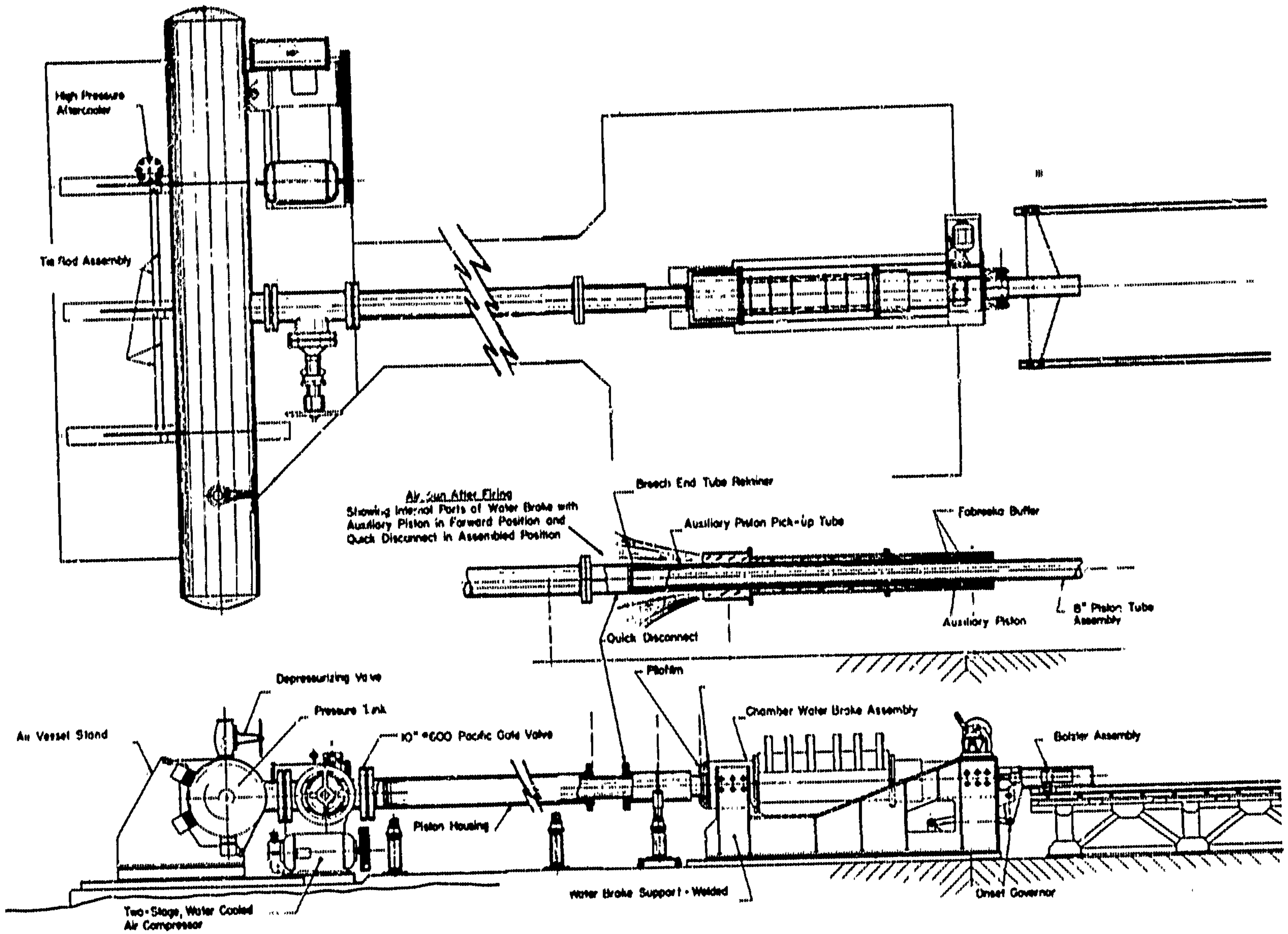


Figure 6. Arrangement of Airgun Components.

TABLE I

PERFORMANCE CHARACTERISTICS OF THE DAISY DECELERATOR

I. Airgun:

1. Designed to accelerate sleds weighing from 250 lbs to 2000 lbs. Has been used successfully for sleds weighing more than 5500 lbs.
2. Designed to provide sled velocities of between 30 ft/sec and 175 ft/sec. Has been used at velocities of between 10.7 ft/sec and 176 ft/sec.
3. Acceleration level less than 20 G for a maximum velocity test. Lower acceleration for lower velocity (approximately proportional to V^2).
4. Acceleration distance fixed at 42 ft.
5. Acceleration onset less than 500 G/sec.

II. Test Sleds:

Sled No.	Payload Weight	Basic Sled Weight	Design G	Ultimate G
1	350 lbs	465	200	400
2	*	1410	*	*
3	250 lbs	1975	171	513
4	250 lbs	3800	100	300
5	250 lbs	1950	171	513
6	1000	4830	25	100

*Depends on payload and adaptor configuration. See Text.

III. Water Brakes:

Brake No.	Braking Distance	Design Brake Force	Ultimate Brake Force
1	48 in.	200,000 lbs	600,000 lbs

with, the sled. The operation can be best understood by reference to Figure 7. The bolster contacts the sled and transmits the thrust from the thrust piston to the sled. Extensions of the bolster carry slippers which ride on the track rails and support the forward end of the thrust piston as it extends. The thrust piston is a hollow tube, closed off at one end by the bolster and provided with a sliding lip seal at the other end. This prevents loss of air between the thrust piston and the thrust piston housing. During pressurization, the bolster end of the thrust piston is held by a lever of the "onset control mechanism" which prevents the thrust piston from moving under the action of increasing pressure. Once the required pressure is obtained, and all preparations for the test have been completed, the onset control mechanism is de-energized, releasing the thrust piston. The high pressure air within the system, acting on the effective area of the piston, moves the thrust piston forward. This moves the sled forward at increasing velocity. At the end of its travel, the thrust piston is stopped by a special thrust piston brake and the sled coasts along the track until it engages the sled waterbrake.

The thrust piston is a hollow aluminum tube, about 60 feet long and 8 inches outside diameter. Of this length, about 10 feet are needed because of the space required for the thrust piston brake, and about 8 feet are required to decelerate the thrust piston. This leaves 42 feet effective length to accelerate the sled. This distance remains constant for all tests. Variations in velocity are achieved only by changing the pneumatic pressure in the system.

The thrust piston housing acts as the cylinder for the thrust piston, and has a 10 inch inside diameter, giving an effective piston area of about 78.5 square inches. This area is divided between the area at the bolster end (about 42.7 square inches), and the annular area between the thrust piston and the thrust piston housing at the lip seal end. Only the pressure acting on this annular area is transformed into compressive force on the thrust piston thus reducing the problem of buckling of this long tube. This

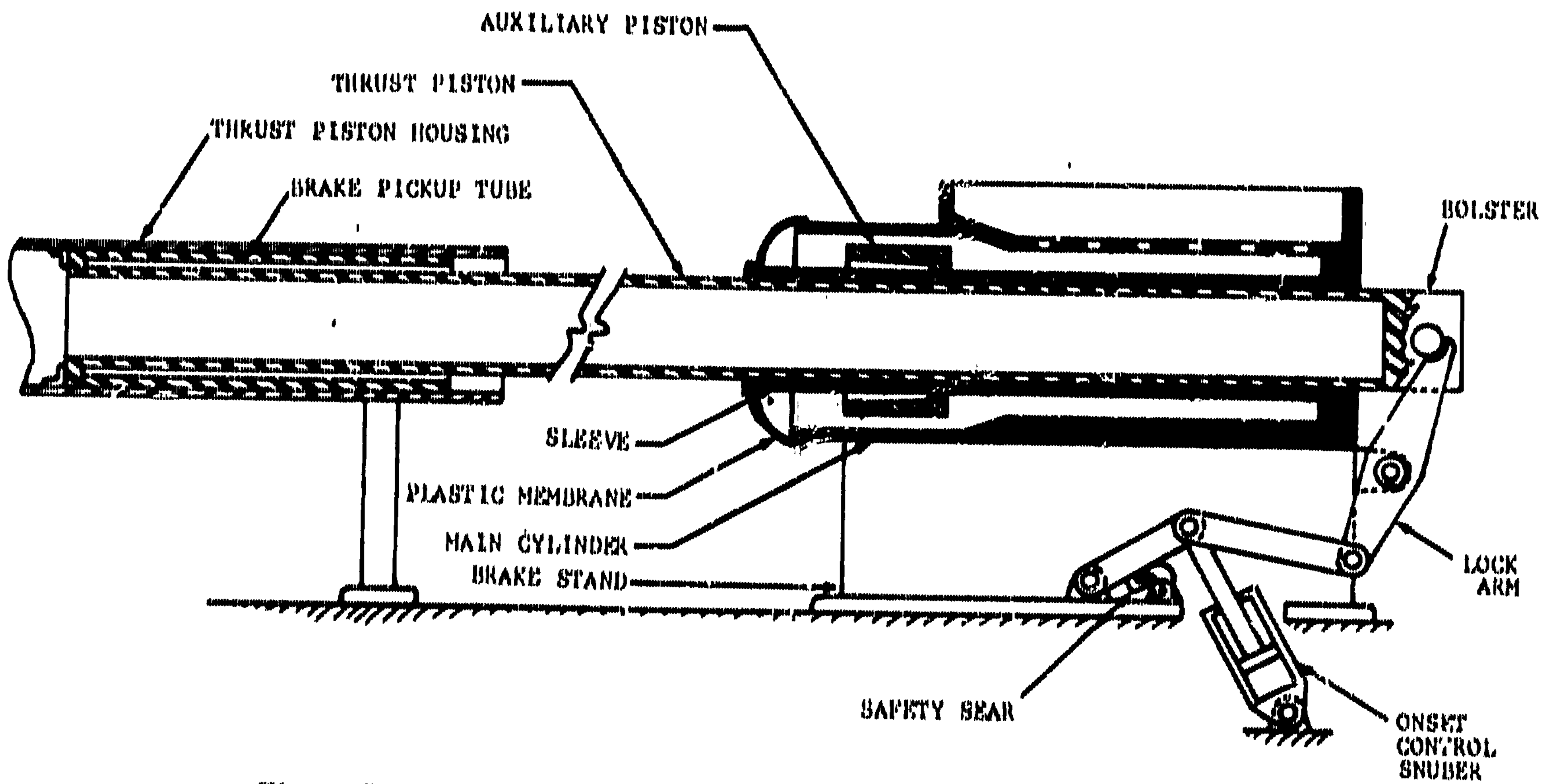


Figure 7. Air Gun Piston Brake and Onset Control (not to scale)

arrangement of the hollow thrust piston also permits the space within the tube to act as additional air storage volume. The air storage tank holds approximately 80 cubic feet, and the thrust tube holds about 20 cubic feet, giving a total reservoir volume of about 100 cubic feet. The two stage, 40 hp air compressor can pressurize the storage tank to 560 psi in about 75 minutes. Most tests are accomplished with considerably lower pressures, so that pressurization is not the limiting factor in establishing turn around time. A gate valve is provided to retain residual air in the tank after firing, so that the thrust piston may be retracted after bleeding off only the air in the thrust piston housing and thrust piston. The gate valve also provides some measure of safety in operation, since it remains closed until a few seconds before the test. Thus, the airgun piston is at ambient pressure, and safe, during all sled preparations.

The airgun waterbrake operates through the use of an auxiliary piston. Although the description of the waterbrake operation is somewhat involved, the operation itself is simple. The thrust piston passes through a sleeve in the airgun waterbrake. The sleeve has three functions: it acts as support for the thrust piston, it guides the auxiliary piston, and it serves as an attachment point for a thin frangible plastic membrane. This plastic membrane, annular in shape, is taped at its inner edge to the sleeve, and at its outer edge to the main cylinder of the airgun waterbrake. It retains water in the main cylinder until required for braking action. As the thrust piston approaches the end of its travel, a brake pick up tube, attached to the seal end of the thrust piston, breaks the plastic membrane and engages the auxiliary piston. The auxiliary piston then moves forward with the thrust piston, forcing water ahead of it out through a series of holes in the upper part of the main cylinder. The exchange of energy from the moving piston to the moving water serves to stop the piston.

The "onset control mechanism" is used to gradually release the thrust piston. A hydraulic cylinder is connected to the bolster through a series of levers arranged so that pressure

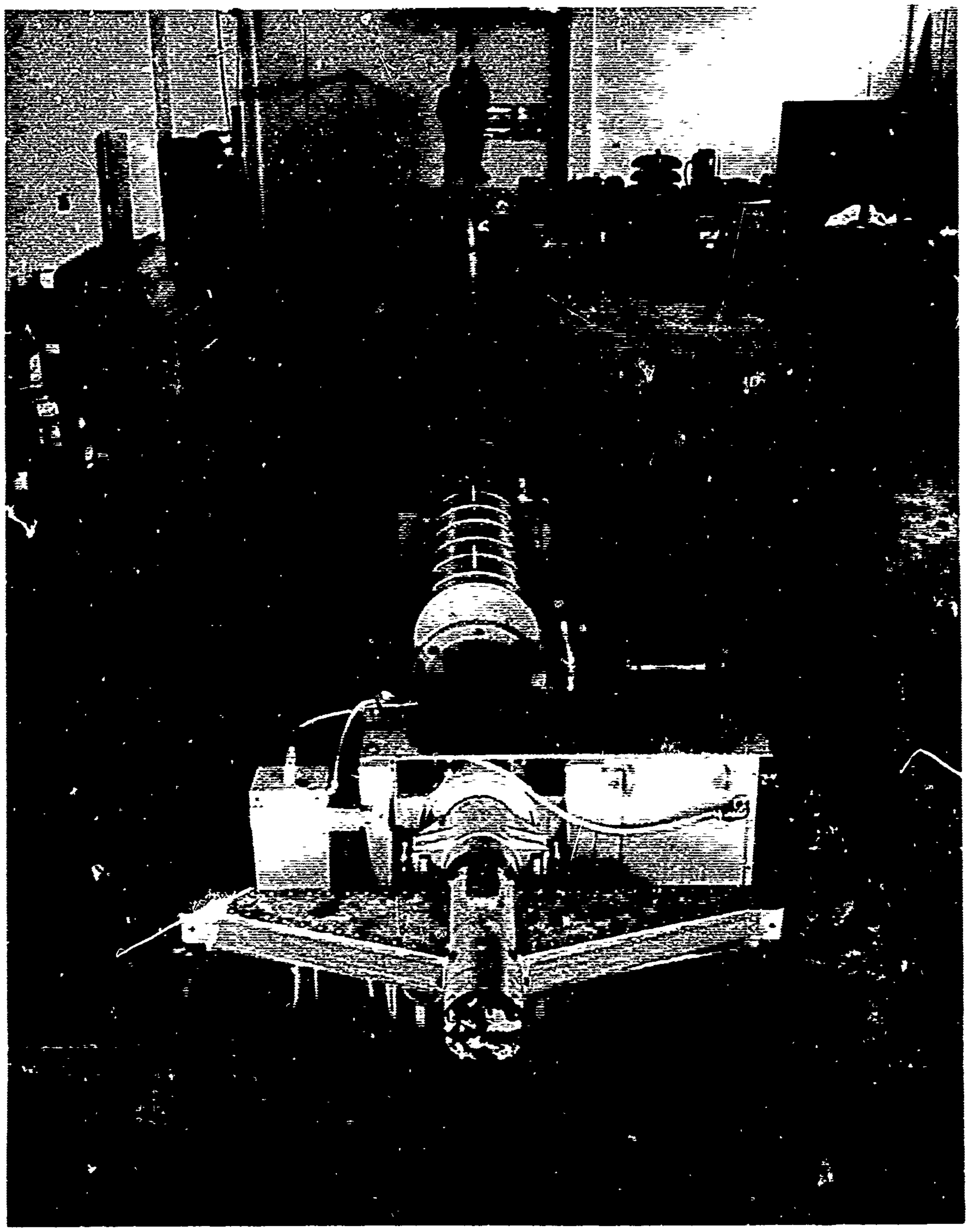


Figure 8. Airgun View From Bolster to Air Tank

maintained within the cylinder will hold the bolster, and thus the thrust piston, in place. When it is desired to fire the airgun, the hydraulic pressure into the cylinder is released. The cylinder then acts as a hydraulic shock absorber to regulate the movement of the levers and release the bolster. This regulation is designed to assure that the sled will be accelerated with an onset rate of less than 500 G/sec. A safety sear is provided to prevent premature release in the event of power failure.

The fire control panel, Figure 9, is located in the test control building. This panel contains the control switches for pressurization and firing, gages to monitor air pressure in the thrust piston housing and the main storage tank, "ready lights" for all necessary preparations, safety circuits and interlocks, and communication controls.

C. Sled Number 1 (Figure 3)

This is the sled originally furnished for the Decelerator. It is designed to decelerate a payload of 350 lbs at 200 G. A minimum factor of safety of 2 was used in the design. The sled consists of a tubular truss built around a four-inch diameter primary structural element. All tubing is AISI 4130 chromium molybdenum steel, stress relieved after welding with no further heat treatment. A 66 inch diameter, 2 inch thick plywood table can be bolted to the top of the truss to form an attachment plane for the test items. This table is removable to permit fastening the payload directly to the truss.

The slippers for this sled provide the bearing between the sled and the rails, and are typical of the slippers used on all Daisy Decelerator test sleds. The slippers encircle the cylindrical rails for approximately 270 degrees, with the remaining 90 degrees providing clearance for the rail supports. The slippers have limited movement in the pitch and yaw degrees of freedom, and vertical and transverse adjustment is provided by means of shims. A replaceable bearing insert of bronze is used. This insert has a tapered leading edge. Prior to each test, the rails are coated

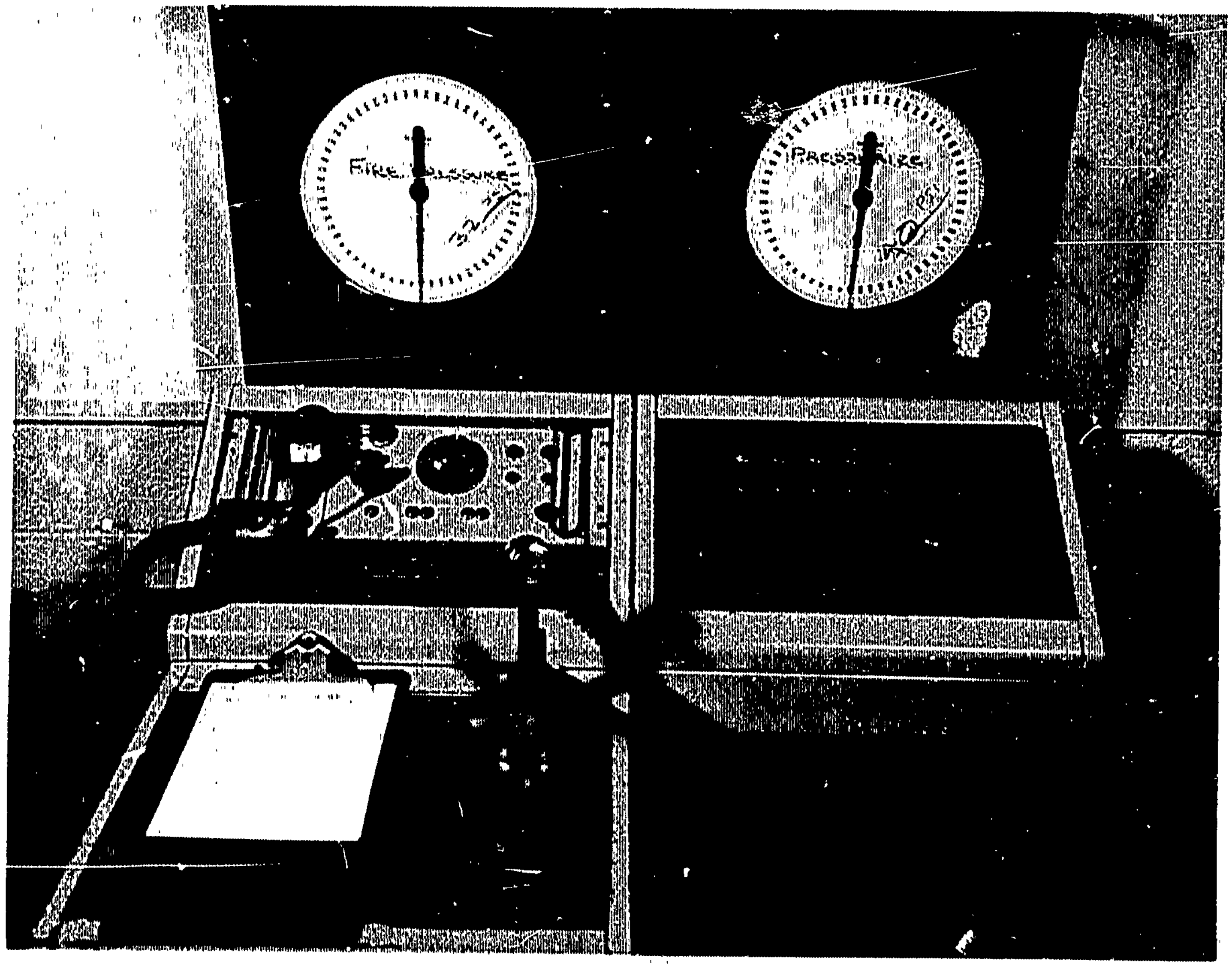


Figure 9. Fire Control Panel. Gages for tank pressure (right) and fire pressure (left) are shown. Check list used during countdown procedure is on clipboard.

with a thin silicone base oil. As the slipper passes over the rail, the tapered leading edge enables an oil film to be built up between the bearing and rail. This reduces the velocity loss du(.o friction and slipper wear due to abrasion. Normally several hundred tests can be accomplished before replacement of the bronze inserts is required.

D. Sled Number 2 (Figure 10)

This vehicle was originally designed to carry a reinforced aircraft type seat positioned in a vertical plane. After considerable use, including programs which stressed the structure beyond the design specifications, this sled was repaired and modified into a general purpose flat topped test vehicle. It now serves as a device for testing unusual payloads, for non-human testing at high levels, or for tests in which failure of the equipment test item could cause damage to the sled.

E. Sled Number 3 and Sled Number 5 (Figure 11)

These sleds are exact copies of the original Number 2 configuration. A tubular truss framework carries a steel aircraft seat similar in configuration to the MIL-S-9479 upward ejection seat and is supported on the track by four slippers (31). To reduce the magnitude of eccentric loads upon the structure, the seat is placed deep in the structure so that the center of gravity of the sled and test subject lies along the axis of the brake piston. The seat itself can be rotated about a transverse axis passing through the center of gravity of the combined mass of man and seat. This arrangement permits adjustment of the seat through an angle of 360 degrees in the vertical pitch plane, with positive lock each 10 degrees. The seat may be placed in either a forward facing ($-G_x$) or backward ($+G_x$) facing position (?). The sleds are designed to carry a human test subject weighing 250 lbs at a deceleration level of 171 G's while maintaining a factor of safety of three.

The seat is easily removable so that it may be replaced with individual contour couches for high level deceleration work, or with spec'ally designed fixtures for unusual test requirements.

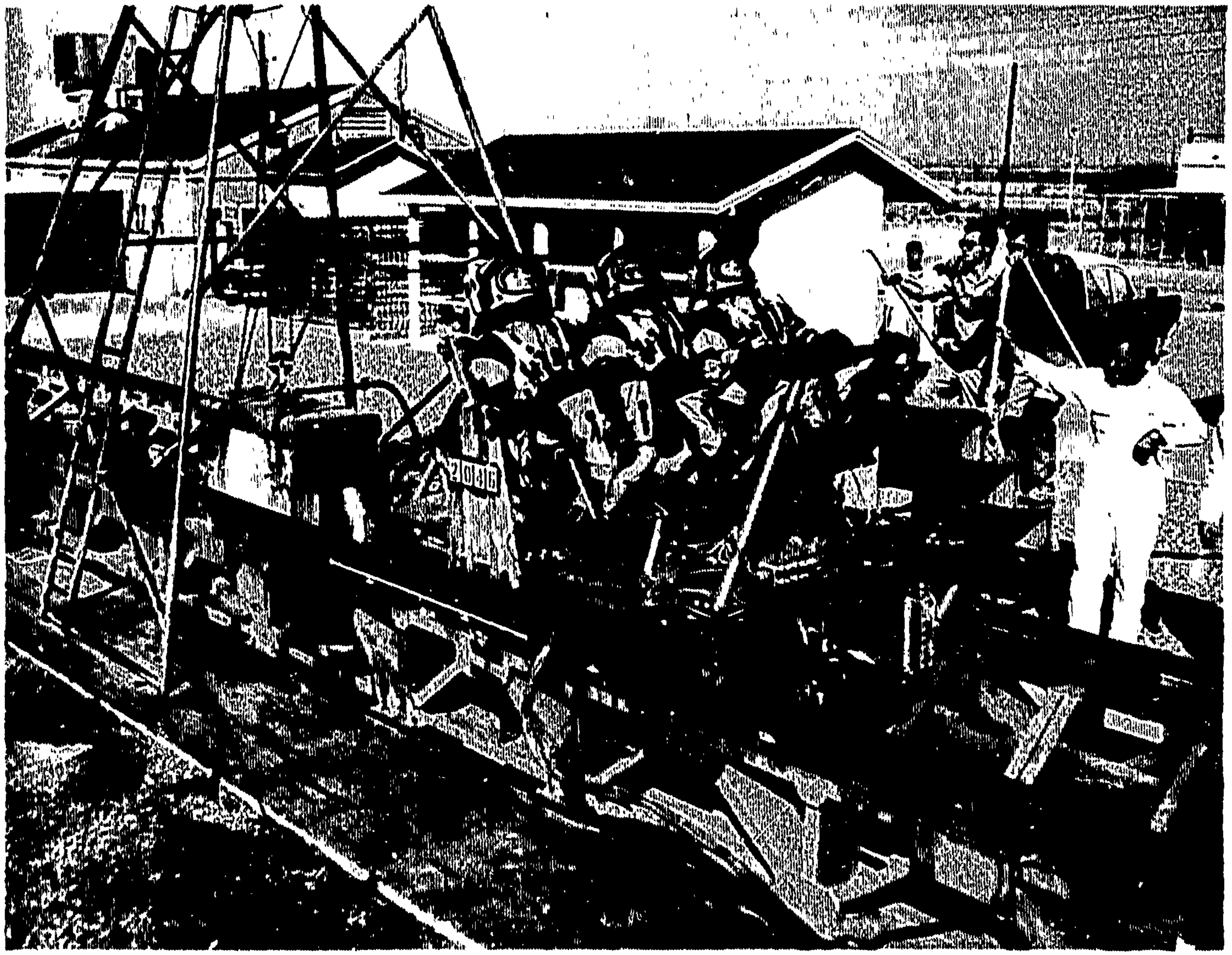


Figure 10. Sled Number 2, Modified for Testing Spacecraft Support-Restraint Systems. In these tests it was necessary to use three volunteer subjects simultaneously. To keep the sled center of gravity in alignment with the waterbrake, it was necessary to add ballast to the bottom of the sled, resulting in a test weight of over 5000 pounds.

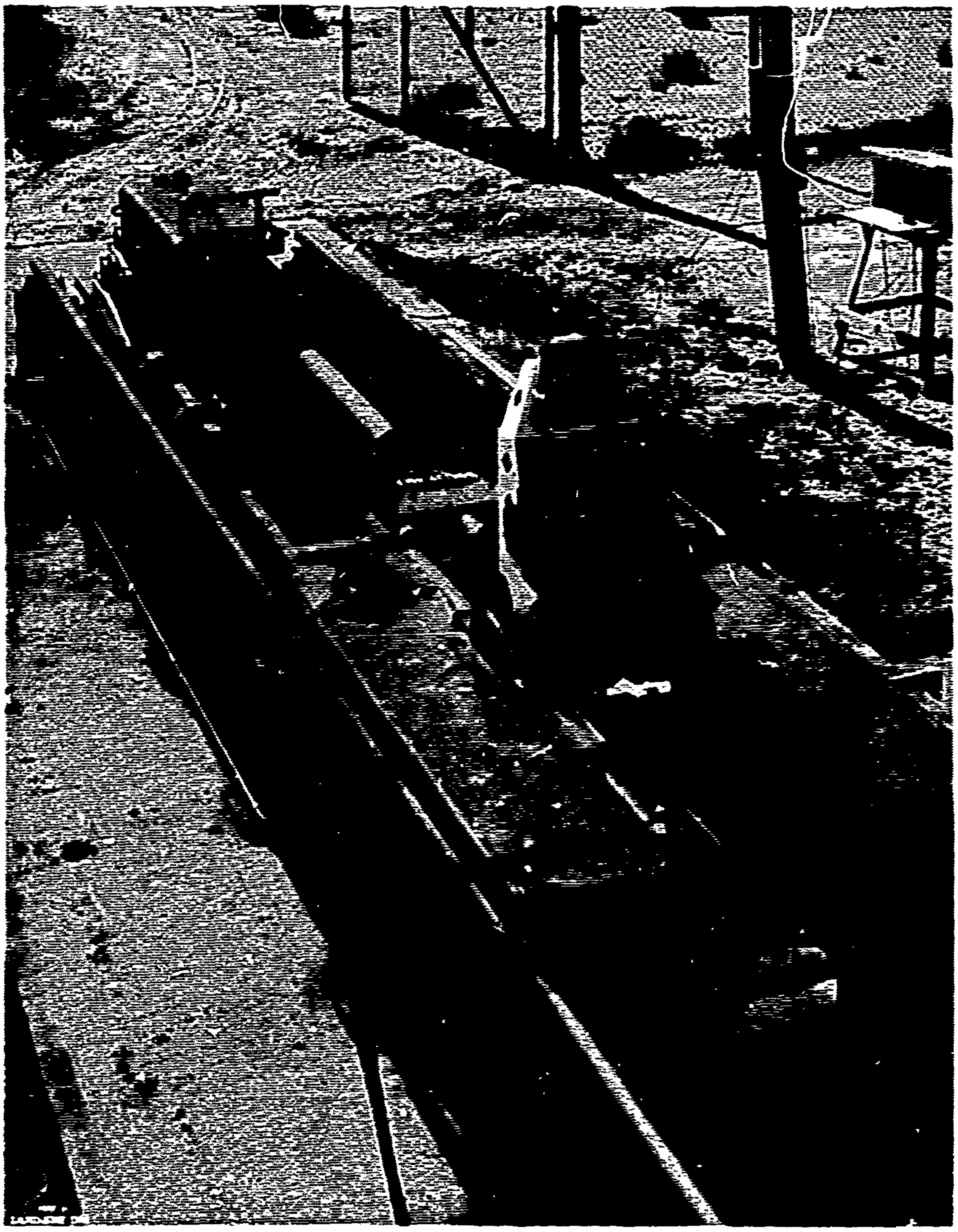


Figure 11. Sled Number 3 Similar to Sled Number 5) is Shown Just in Front of the Waterbrake.

F. Sled Number 4 (Figure 12)

This sled is designed (33) to fulfill the requirement for human tolerance testing along an axis of deceleration other than provided by the Number 3 sled. It provides for adjustment of the seat along the roll and yaw axis as well as the pitch axis.

This sled consists of the following major components:

(a) The subject seat, similar to that used on sled Number 3.

(b) The gimbal assembly which holds the seat and provides two axes of rotation (roll and pitch).

(c) The ring, which provides rotation of the gimbal and seat assembly about the vertical axis (yaw).

(d) The brake piston which enters the waterbrake and transmits the decelerating force.

(e) The slippers which provide a sliding bearing between the sled and the rails.

The seat configuration is similar to the MIL-S-9479 upward ejection seat, but built of high strength steel plate to withstand the high deceleration loads. It weighs approximately 280 pounds.

The gimbal assembly is built of 7075-T6 aluminum alloy rivited together to form a hollow box section for light weight and rigidity. Reinforcements are located internally where required to carry the bending and torsional loads generated under some test conditions. Its weight is 480 pounds.

The ring is of similar construction; i.e., a hollow rectangular box section built of 7075-T6 plate and extrusions, rivited together. It carries 36 equally spaced 7/8 inch holes on a 101.7 inch diameter bolt circle to enable positioning the gimbal and seat in any yaw position provided by the 10-degree increments.

The truss, slippers, and brake piston are of conventional design and construction, whose pertinent features can be obtained from the illustrations.

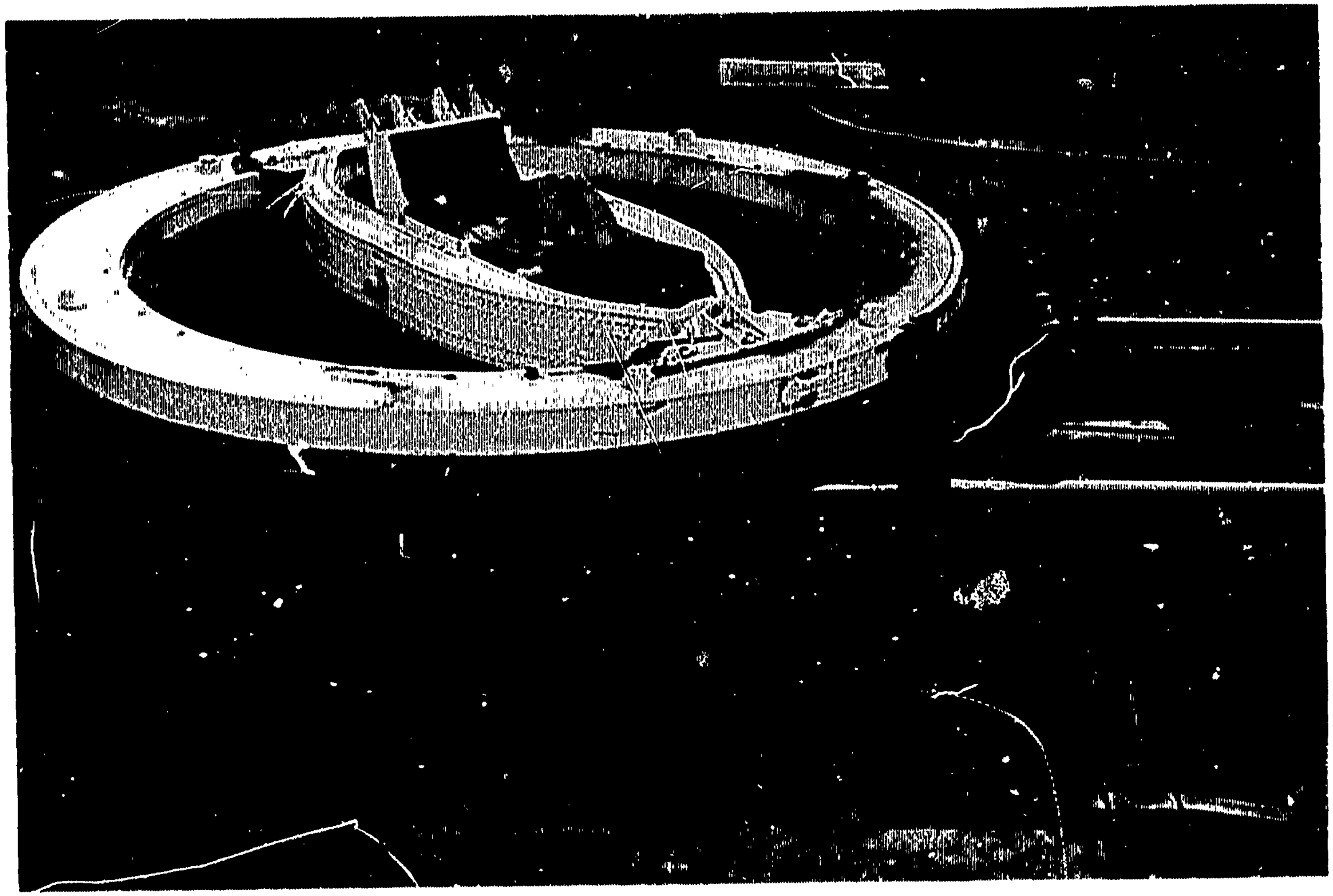


Figure 12. Sled Number 4. In this view, the arrangement of ring, gimbal seat and the rigid steel truss which supports the ring and transmits the brake load from the probe is shown.

Sled Number 4 was designed to meet the following criteria:

1. Test subject weight, including personal equipment, while seated in the sled: 250 lbs.
2. Maximum test deceleration: 100 G.
3. Factor of safety (on ultimate); 3.
4. Increment roll, pitch and yaw positioning of test subject, with any combination of roll, pitch and yaw, through 360 degrees at 10-degree increments.

In consequence of the design concept of this sled, it can also be used for testing large or special payloads simply by removing the seat and gimbal and replacing them with a special adaptor which carries the payload in place (Figure 13).

In order to identify the seat position on this sled, a simple numbering system is used. The general arrangement of the ring, gimbal and seat is shown in Figure 14. The 36 holes in the ring permit the gimbal to be located to provide 10-degree increments of yaw. The gimbal rotates about a pivot in its end fittings, to provide roll orientation, also by 10-degree increments. Pitch adjustment is provided by a pivot between seat and gimbal.

To describe the various positions of the gimbal end blocks, the gimbal and the seat, the following system is used:

The ring, gimbal blocks and gimbal are assigned numerical designations corresponding to each 10 degrees of adjustment. The progression of the numbers is such that:

(a) For the ring, 0 degrees is the position just behind the probe and the positions increase in 10-degree increments clockwise around the ring as viewed from above. This provides the yaw designation.

(b) For the gimbal block the numbers begin at 0 degrees with the gimbal in the flat position and increase clockwise as viewed by an upright subject looking towards the forward gimbal mount, providing roll designation.

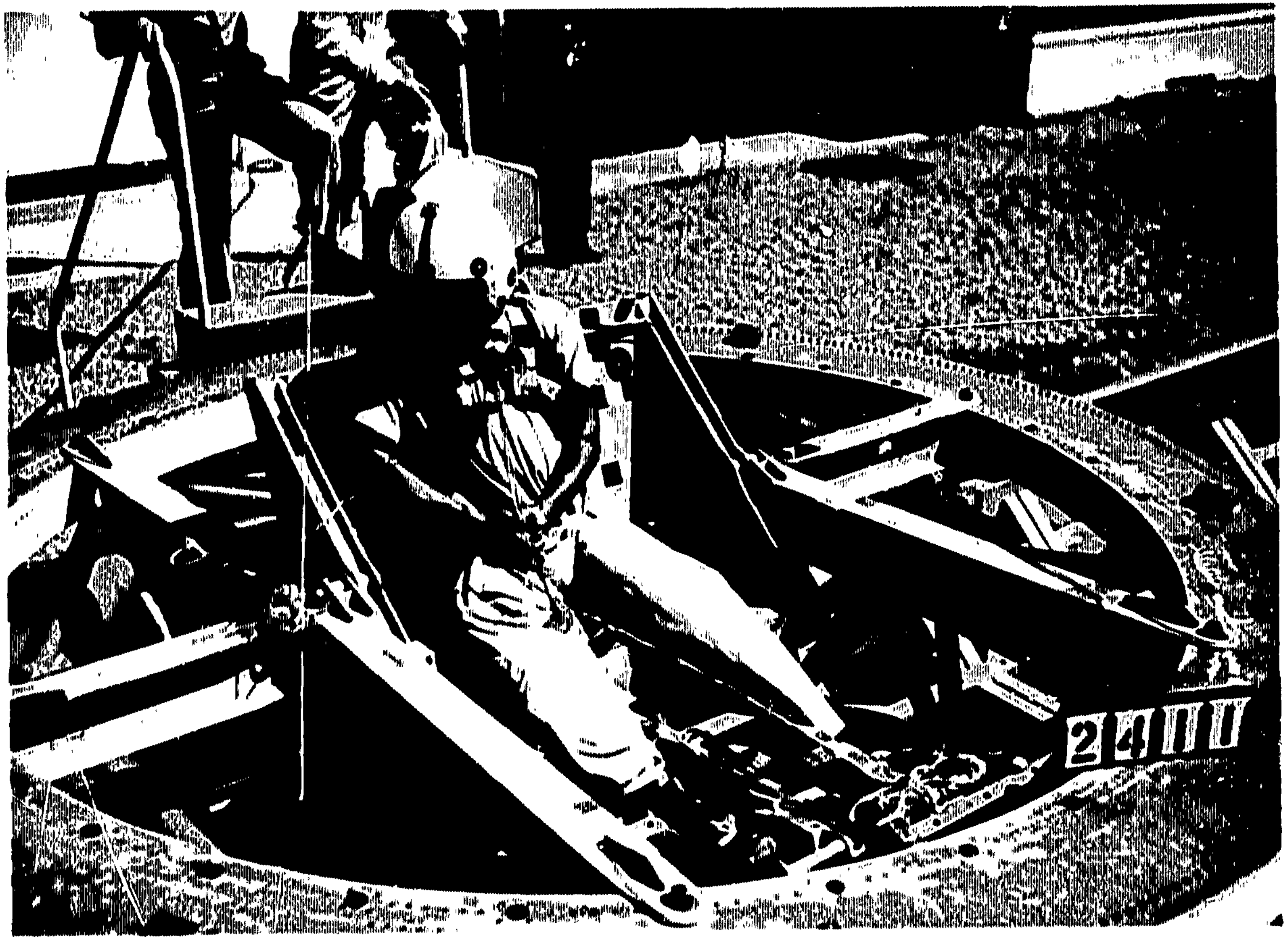


Figure 13. Sled Number 4 Seat Modification. The usual gimbal-seat assembly of sled Number 4 can be replaced with various test devices to meet special conditions. For the test shown, it was important to provide lateral clearance for unrestricted lateral motion. The special seat shown provided the required clearance.

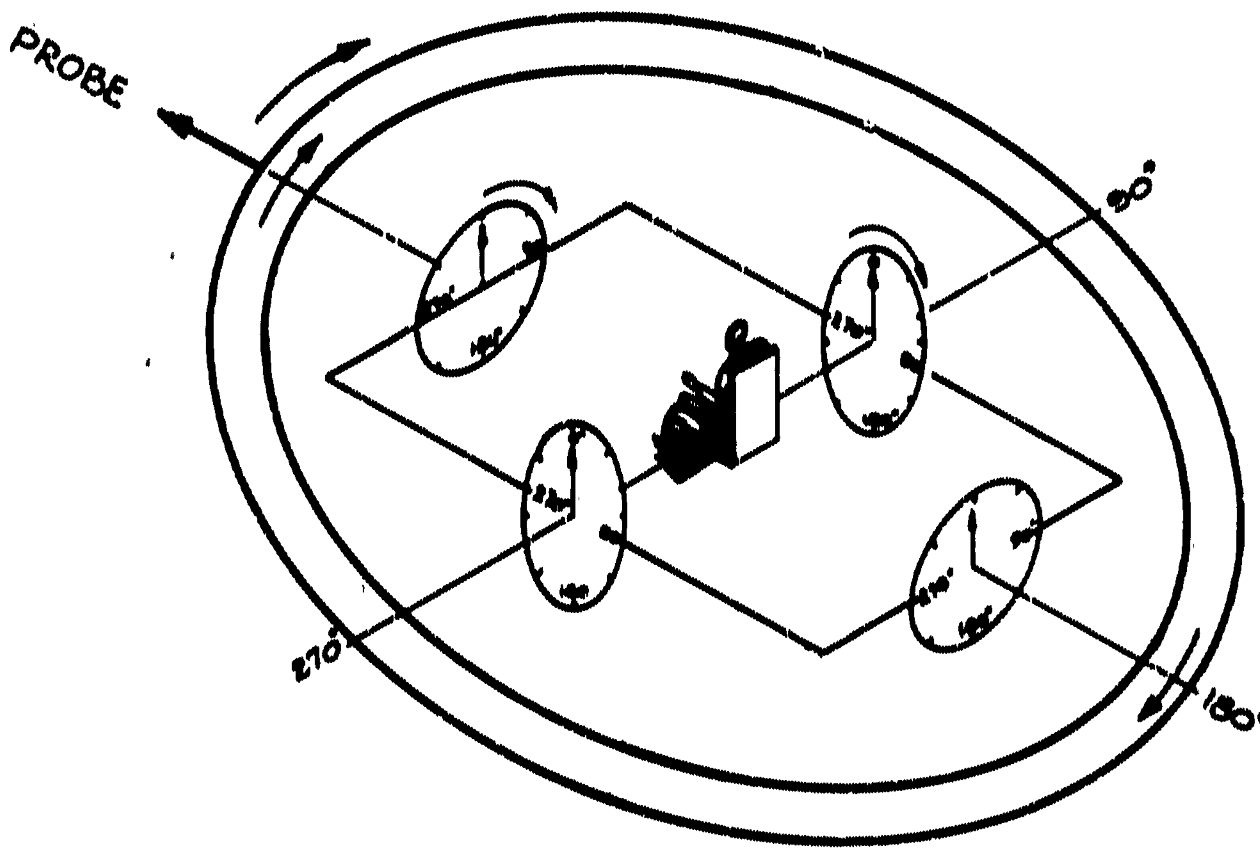


Figure 14. Orientation Guide for Sled No. 4

(c) For the gimbal, the numbers begin with 0 degrees with the seat back in the true vertical position (gimbal horizontal) and increases as the seat is tilted back. This establishes pitch designation. Because of a 5-degree angle between the seat back and the adjustment hole pattern, it is necessary to specify the seat position in 5 degrees, 15 degrees, 25 degrees, etc., designations, with 5 degrees or 355 degrees being as close to vertical as is possible.

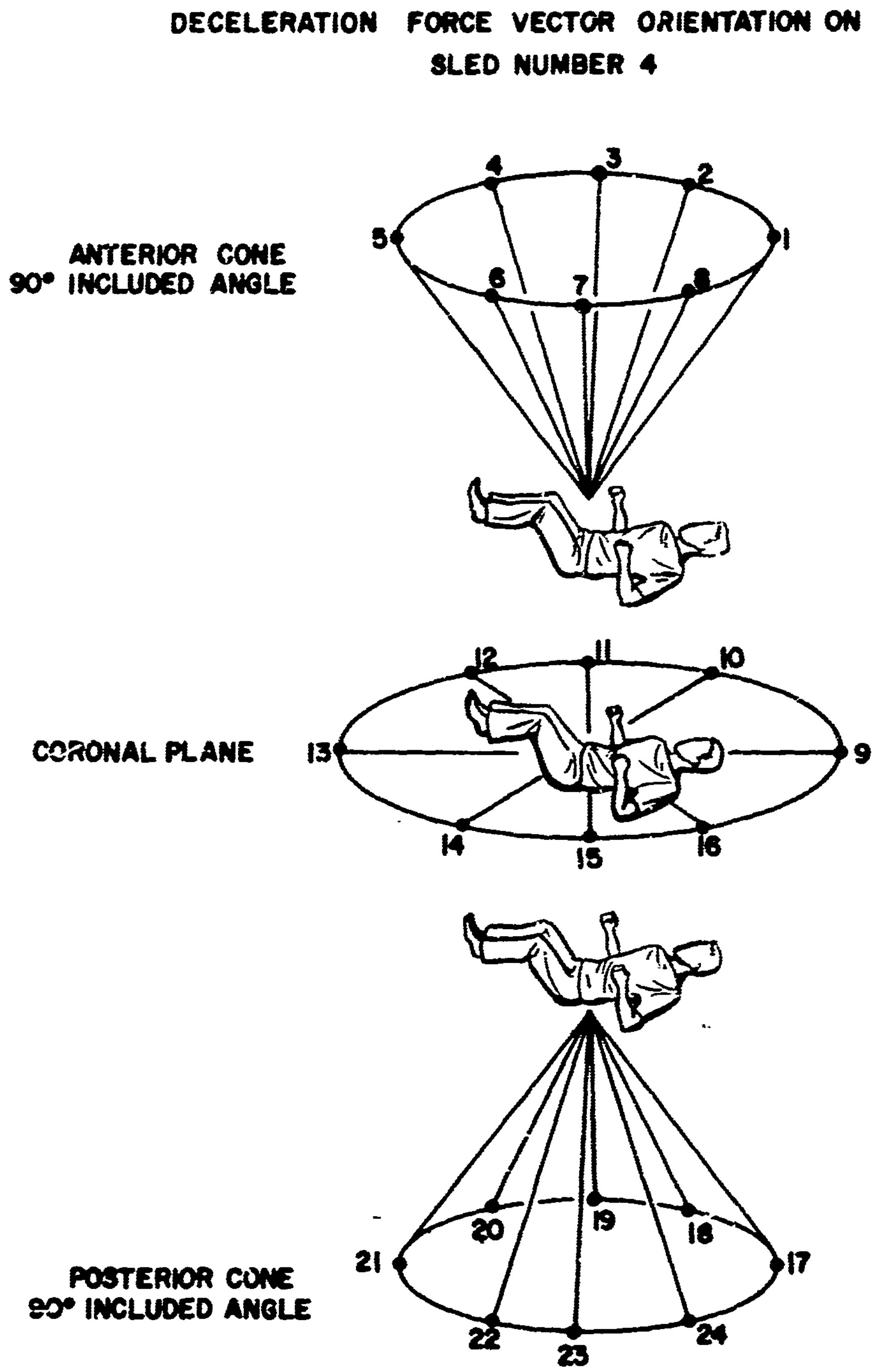
The orientations of the roll, pitch and yaw positions are specified by stating the gimbal block, gimbal, and ring numbers in that order.

This designation system corresponds to stating the conventional roll, pitch and yaw orientations of the subject with respect to a normally upright subject looking forward. Only positive position designations are used to avoid operational confusion.

Figure 15 gives the seat position nomenclature for several typical positions. The impact force vectors in this figure are directed toward the subject. The locus of the anterior and posterior cone vectors is a cone of 90 degrees included angle. The 8 vectors shown are distributed equally around the cone. Not shown are the $-G_x$ position (0-5-0) and the $+G_x$ position (0-5-180). Some of the positions shown are "best fit" to the exact geometrical position shown in the sketch, as limited by the availability of adjustments. More than one arrangement can be used to provide the required position. The ones shown are those used most often.

G. Sled Number 6 (Figure 16)

The purpose of this sled is to simulate Apollo space capsule crew couch attachment points in proper orientation with regard to the impact force. Using the same nomenclature as developed for sled No. 4, positions of 0°, 60° and 90° pitch, and 30° increments of yaw can be achieved. The sled will test prototype support, restraint and attenuation systems, compatible with the attachment points and weighing up to 1000 lbs, to 25 G with a factor of safety of 3 to the yield point of the material.



VECTOR	Sled Position ROLL	PITCH	YAW
1	0	315	0
2	0	335	330
3	0	005	320
4	0	035	330
5	0	045	0
6	0	035	030
7	0	005	040
8	0	335	030
9	0	085	180
10	0	085	220
11	0	085	270
12	0	085	320
13	0	085	0
14	0	085	040
15	0	085	090
16	0	085	140
17	0	045	180
18	0	035	210
19	0	005	220
20	0	335	210
21	0	315	180
22	0	335	150
23	0	005	140
24	0	035	150

Note: Deceleration force acts toward subject

Figure 15. Standard Omnidirectional Positions for Sled Number 4.

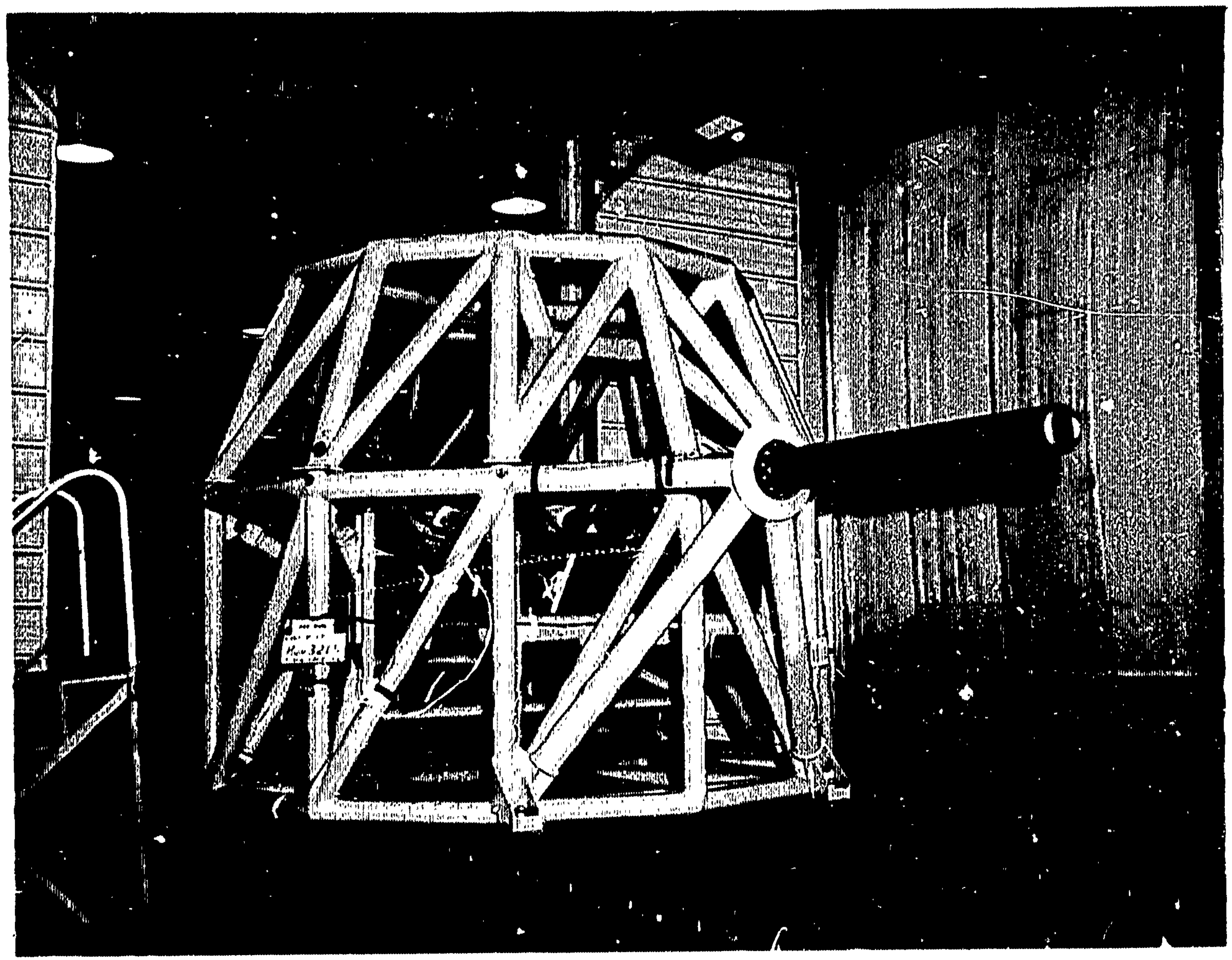


Figure 16. Sled Number 6 with a Prototype Space Capsule Crew Support and Restraint System Installed.

The structure is a standard welded truss of AISI 4130 steel tubing. To achieve the variation in yaw position, the upper half of the sled structure was designed so that it may be assembled to the lower half at 30° increments of yaw. This upper half carries all of the couch attachment points for the 60° and 90° pitch positions. Additional adaptors are required to accommodate the 0° pitch position and to provide bearing surfaces for the lateral ($\pm G_y$) loads. These may be attached in the lower half at a position corresponding to the yaw position of the upper half.

Because of the space envelope required by the 3-man couches and the various impact positions to be tested, it was necessary to build this sled entirely above the track rails. This resulted in a truss assembly about 10 feet in diameter and rising 10 feet above the rails. The center of gravity of the sled, couches and test subjects is thus above the line of the deceleration force normally applied by the waterbrake. To avoid large overturning moments caused by eccentricity between the test item center of gravity and the line of application of the braking force, it was necessary to raise the waterbrake until the decelerating force was in line with the center of gravity. To accomplish this, a "water brake spacer", 52.75 inches high, is placed between the water brake and the water brake attachment rails on the track foundation (Figure 17).

To ease the operational difficulties of aligning the sled with the waterbrake, this sled has incorporated screw adjustments rather than shim adjustments for vertical and lateral positioning of the slippers.

H. Waterbrake (Figure 18)

Perhaps the most important mechanical component of the Daisy Decelerator is the waterbrake. This assembly has two major parts, the waterbrake cylinder and a piston which is part of the sled and enters the waterbrake cylinder. The operation of the brake depends on the transfer of energy from the moving sled to moving water.

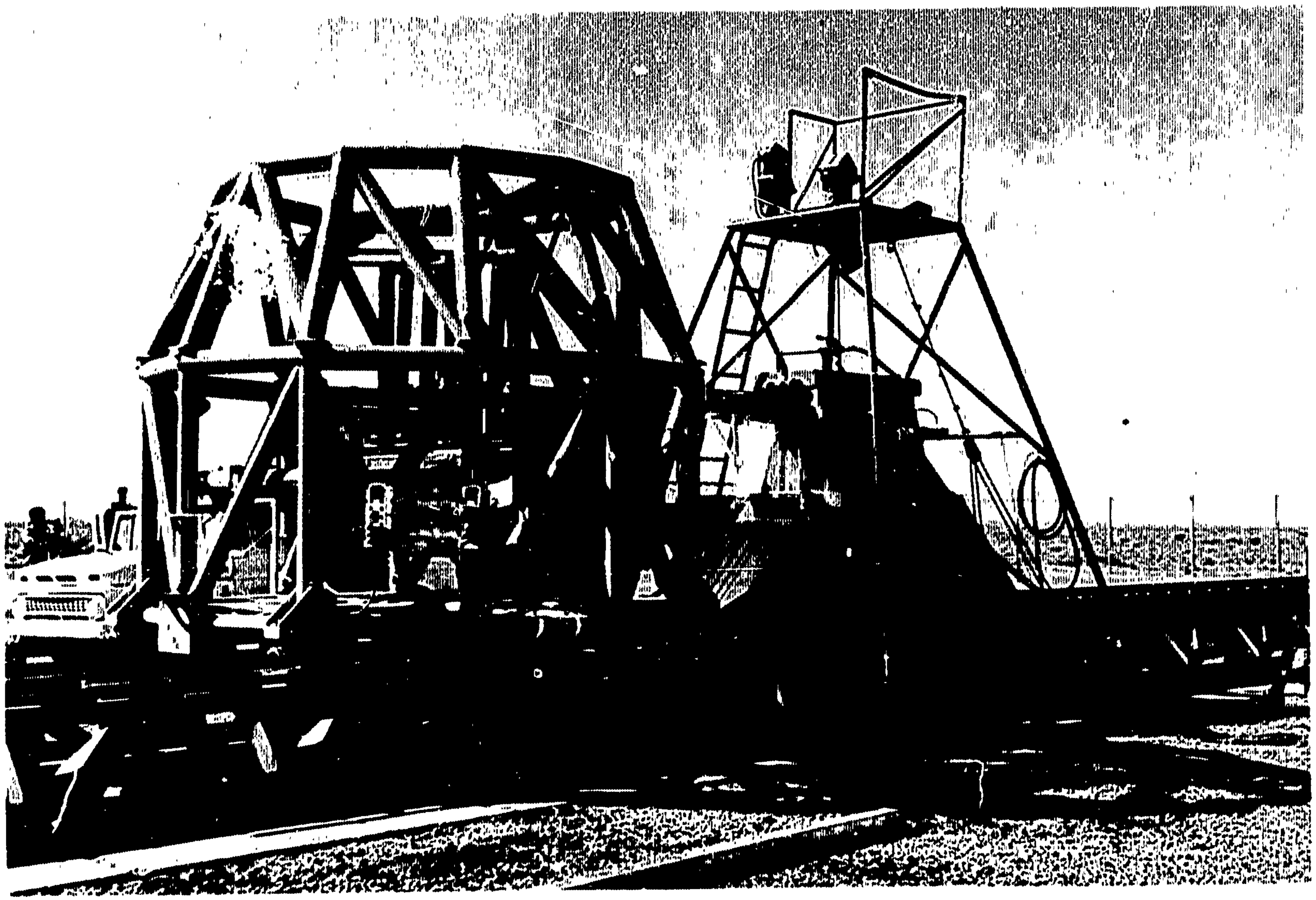


Figure 17. Sled Number 6 During Impact. The spacer beneath the waterbrake lifts the brake so that the braking force is through the sled center of gravity.

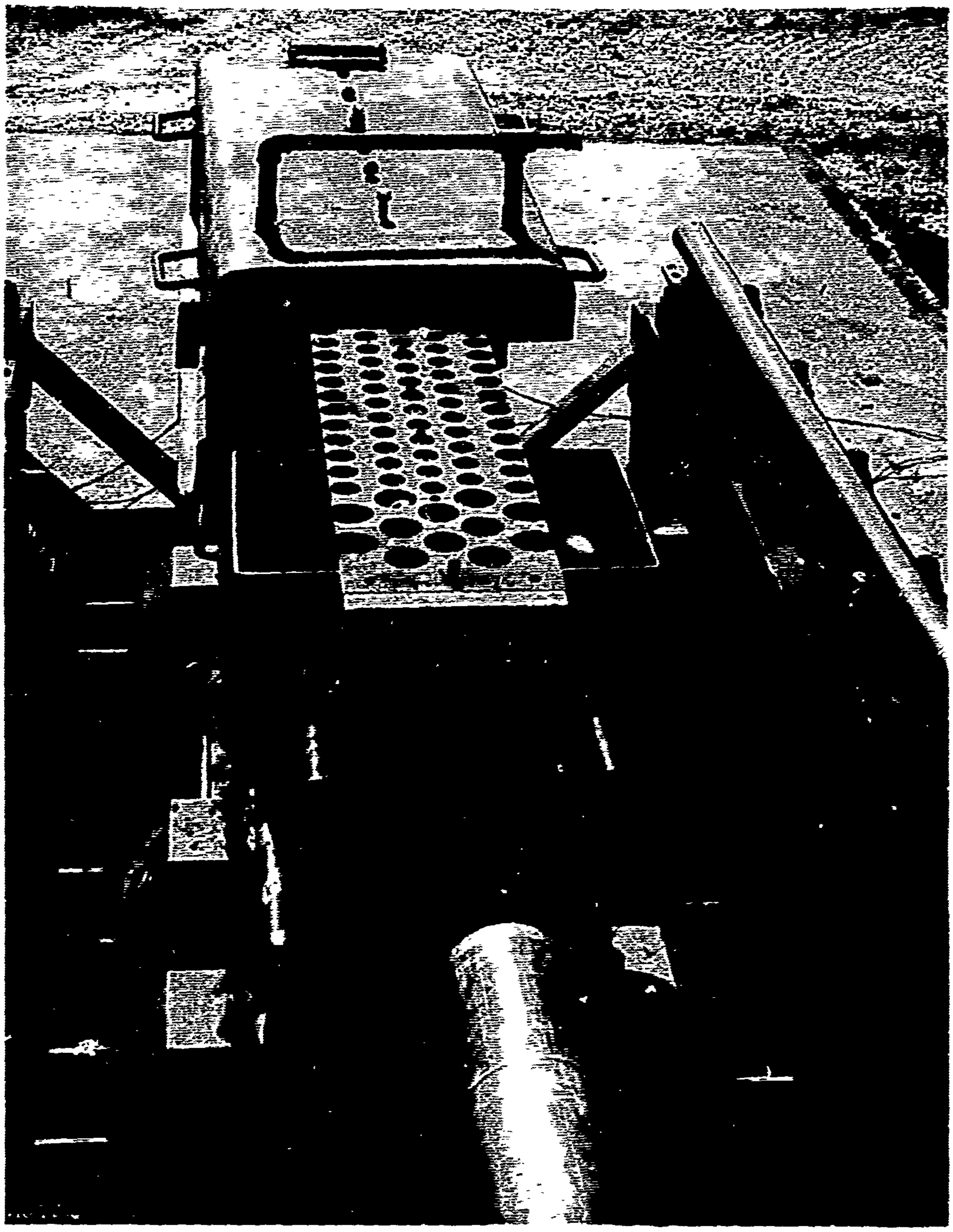


Figure 18. Waterbrake. The spray shield is shown moved to the rear of the brake to expose the water exit orifices. In the foreground the sled probe is positioned to enter the brake. Orifice plugs of various sizes are inserted into tapped radial holes in the brake.

The sled piston, 6 inches in diameter with an effective length of 4 feet, works in the braking cylinder which has a corresponding inside diameter and length. This cylinder is permanently closed at one end and sealed at the other by a thin plastic membrane. Radial holes are drilled in the top portion of the cylinder, along its full length, to allow water to escape as the piston moves through the cylinder. These holes are threaded so that they may receive plugs to either stop the hole completely or restrict the flow to a smaller orifice. Thus the area available for water discharge may be readily varied. A small (0.003 inch) clearance is maintained between the piston and the cylinder, so that leakage is negligible. In addition, a lip seal is provided at the entrance end of the cylinder, and the internal bore of the cylinder is designed to promote pressure drop in any fluid attempting to pass between the piston and cylinder walls. These methods are sufficiently effective that replacement of the lip seal is not required for in excess of 2500 test cycles.

In operation, the required orifice area for escape of the water is calculated and appropriate plugs are installed in the waterbrake cylinder. The piston entrance opening is sealed with the plastic membrane, and the cylinder filled with water.. After the sled has been accelerated to the required velocity by the airgun, it slides freely along the track until the piston attached to the front of the sled engages the waterbrake. The piston breaks the plastic membrane, and the inertia of the sled acts to increase the water pressure in the cylinder. This pressure causes the sled to decelerate and the water to discharge through the orifices. As the piston passes across each orifice opening, the orifice becomes closed off, leaving only the orifices remaining downstream for escape of the water. This provides, in effect, an orifice area which is a function of the deceleration distance.

Knowing the required deceleration time history, velocity and displacement time histories can be readily calculated by simple integration techniques. These can be combined to produce acceleration and velocity displacement histories. With these data and the effective weight of the test sled being decelerated, the required orifice area can be calculated. These calculations

are based upon the First Law of Thermodynamics as applied to a steady flow process, in which compressibility, heat input, work input, changes in internal energy and hydraulic head are assumed negligible. This results in the elementary equation:

$$\frac{p_s}{w} + \frac{V_s^2}{2g} = \frac{p_o}{w} + \frac{V_o^2}{2g}$$

where p = pressure, pounds per square foot

V = velocity, feet per second

w = specific weight of water, about 62.4 pounds per cubic foot

g = standard acceleration of gravity, about 32.2 feet per second per second

and subscript s refers to the magnitudes acting on the sled piston and subscript o refers to the magnitudes just past the brake orifices.

This equation can be rewritten as:

$$V_s^2 - V_o^2 = - \frac{2\,gp}{w}$$

where p is the gage pressure acting on the piston.

From continuity consideration,

$$V_o = \frac{A_s}{A_o} V_s$$

where A_s is the area of the sled piston and A_o is the effective area of the brake orifice openings, both measured in square feet. Using this relationship to eliminate V_o from the energy equation:

$$A_o^2 = \frac{A_s^2\,V_s^2\,w}{2\,gp + V_s^2 w}$$

Within the operating limits of this brake, $V_s^2 w$ is small compared to 2 gp and may be ignored with little error. This permits further simplification so that:

$$A_o = A_s V_s \sqrt{\frac{w}{2gp}}$$

It is known that the pressure acting on the piston must produce the required deceleration force, or

$$p = \frac{F}{A_s} = \frac{WG}{A_s}$$

where F is the deceleration force, W is the effective sled weight and G is the deceleration required, in multiples of g. Substituting into the equation for A_o,

$$A_o = A_s V_s \sqrt{\frac{wA_s}{2gWG}}$$

After substituting the known values

$$A_o = 12.318 \ \frac{V_s}{\sqrt{WG}} \ \text{in}^2$$

This formula, with the previously calculated values for sled velocity and deceleration, is used to calculate the required orifice area as a function of distance in the brake. Experience has shown that the effective orifice area is between one and one-half that of the actual area, depending on test conditions. Orifice plugs are selected to approximate these areas as the sled piston passes through the brake.

I. Instrumentation

The data collection system of the Daisy Decelerator was designed for maximum versatility and reliability under the high deceleration forces encountered in test. On-board recorders and transmitters are used only when special test conditions require them. Instead, signals are transmitted from the sled to the data collection center (Figure 19) through an umbilical

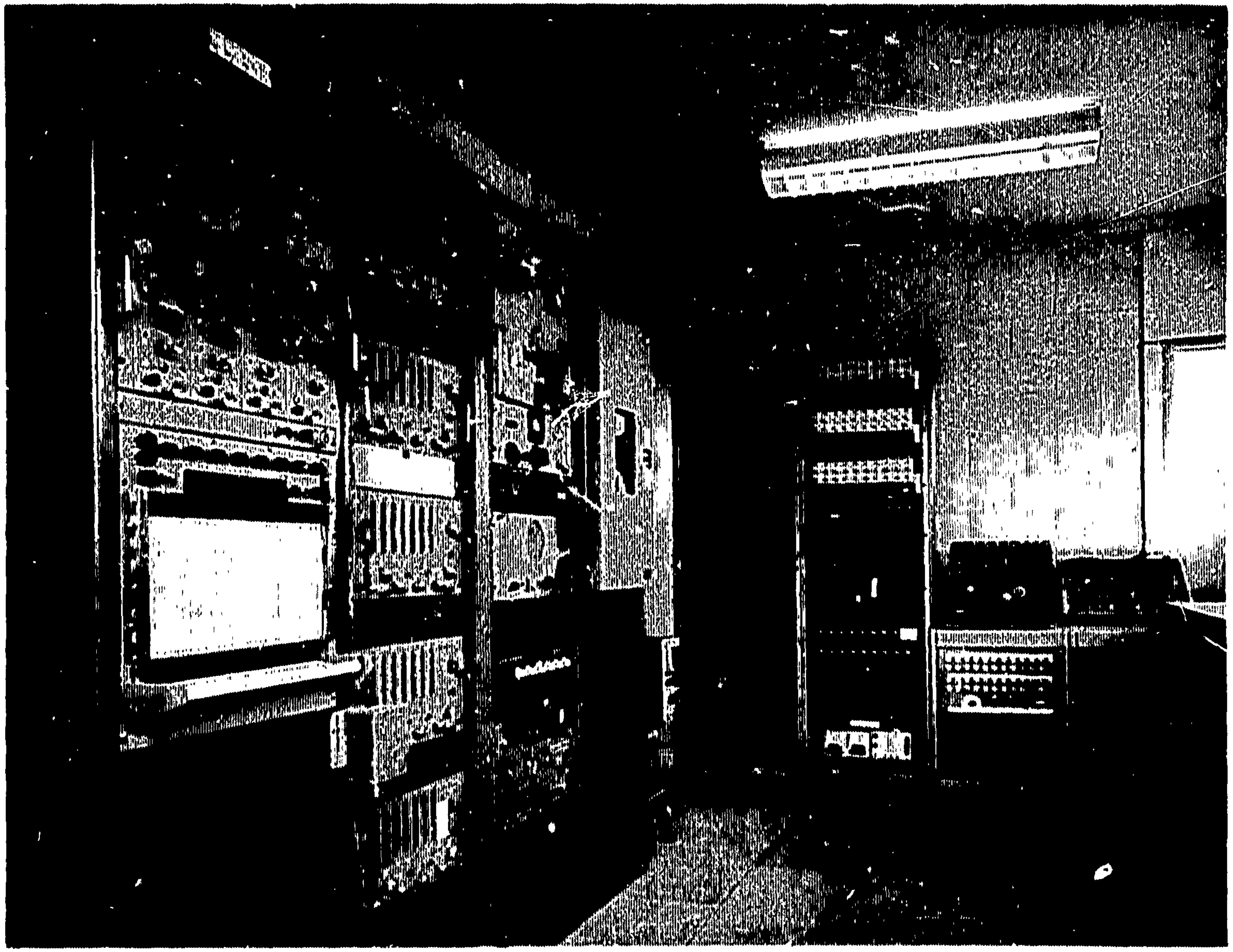


Figure 19. Data Collection System. From left to right, racks contain physiological data amplifiers and recorder, time interval counters, communications electronics and recorder, magnetic tape recorder, junction panel, amplifiers, and oscillograph and calibration system.

cable, one end of which is permanently fastened to the sled and which travels with the sled as it moves down the track. The signal may be put on real time display, recorded on light sensitive paper for quick look data analysis at expanded time scale or recorded on tape for machine data analysis.

The umbilical cable (whip cable) is the electrical link with the sled. It consists of "ALPA" 1329, 27 pair, 54 conductor, #22 stranded wires, approximately 300 feet long. The sled end terminates with Viking VR4-2AG3 connectors which are mounted on a junction panel. The other end terminates at a patch panel in the data collection center. This same patch panel also provides connections for the inputs and outputs of all amplifiers, the tape recorders, the recording oscillographs, the strip chart recorders, and the velocity measurement system. It is thus possible to make any instrument connections desired simply by making the appropriate plug-in connections at this patch panel. Multiple cables are used if the quantity of data requires the additional conductors.

Special provisions have been made for the use of bridge type transducers with an output resistance of less than 1000 ohms. These transducers have proven to be useful and reliable for measuring strain, acceleration, pressure and low frequency vibration, and are commonly used in testing on the Daisy Decelerator. An excitation and balance unit is used which provides independent excitation voltage levels, bridge balance and isolation for each of 24 transducers. Each of these channels is equipped so that dummy resistors can be added when required to complete one or two active arm transducers. Galvanometer shunts may also be added if required. A unique calibration unit is employed. This system provides five point calibration for each of the 24 data channels. Ten turn potentiometers are connected to act as shunt calibration resistors across each bridge. Through proper adjustment of the excitation and calibration controls, provided for each channel, it is possible to obtain quick look data traces which have identical amplitude calibration. This permits ready comparison of data from transducers having different output characteristics, thus facilitating field decisions pertinent to successive tests.

The normal signal level appearing at the transducer output section of the patch panel is usually less than 30 millivolts. This low level signal can be fed directly to a sensitive galvanometer in a recording oscillograph if this is adequate for the test program. However, this signal will require amplification if it must be fed into the tape recorder or high frequency galvanometer. To satisfy these requirements, 30 Redcor Model 361 differential amplifiers are available. These units provide gain adjustments from 10 to 1000, with full scale bandwidth from 0.1 to 100 kHz and with good common mode rejection. This latter feature is necessary because of hum pickup of the unshielded umbilical going to the sled.

Nine Allegany Model 512A DC amplifiers are installed to provide operational amplifiers, integrators and driver amplifiers. These amplifiers have provisions for conversion to various types of operational amplifiers, and are intended to be driven only by the output of the differential amplifiers or the tape playback.

An Ampex Model CP 100 tape recorder is used for signals which are suited for automatic data analysis, for high frequency recording, or when a playback capability is required. This recorder has 14 FM data channels, with record and playback modules for 60 ips tape speed. This gives a bandwidth of DC to 20 kHz. The playback modules permit real time monitoring and recording of the signal, providing quick look data analysis.

Leach MTR 1200 recorders are available for use on the sled, and have been successfully used at impacts up to 177 G with tape speed compensation techniques permitting collection of data during the impact pulse. Both 7 track, 60 ips, and 14 track, 3 3/4 ips recorders are available built to IRIG data specifications(34).

Sled velocity is measured at the airgun-sled separation point and just prior to entrance into the waterbrake. These measurements are made by timing the interval as the sled passes over a known distance. Electrical pulses generated at the beginning and end of this measured distance are used to start and stop Berkeley Model 7360 time interval counters for direct

readout of the time interval, and are recorded on the oscillograph or on magnetic tape for a permanent record. A variety of standard time codes are available for display on the records, and are useful both for timing and for correlation between different records.

High speed (up to 2000 pictures per second) film coverage is used to provide a detailed visual record of the events occurring during impact. On-site processing permits these films to be reviewed within one hour after the test, if desired. Photometric cameras are used to permit analysis of displacement, velocity and acceleration of selected points on the test subject. A Field Emission Module 233, 300 kv x-ray unit is available to determine internal displacements during the test.

III

FACILITY PERFORMANCE

The performance of the Daisy Decelerator is limited only by the ability of the airgun to produce the required impact velocity and of the waterbrake to provide the necessary deceleration force and displacement. Other limitations are associated with the design and structural ability of the test vehicle, whether it be one of the sleds currently available at the facility and adapted for the payload undergoing test, or a sled designed specifically for the payload and test requirement.

Table I lists the pertinent design and operational limitations of the currently available facility components. In this table, "design" refers to the value chosen as an operational limit at the time of the design and structural analysis of the component, and "ultimate" refers to the level at which structural failure could be expected to occur.

Figure 20 shows the combined performance limits of the facility when producing an ideal rectangular impact pulse. The area to the left of the velocity and displacement limit lines,

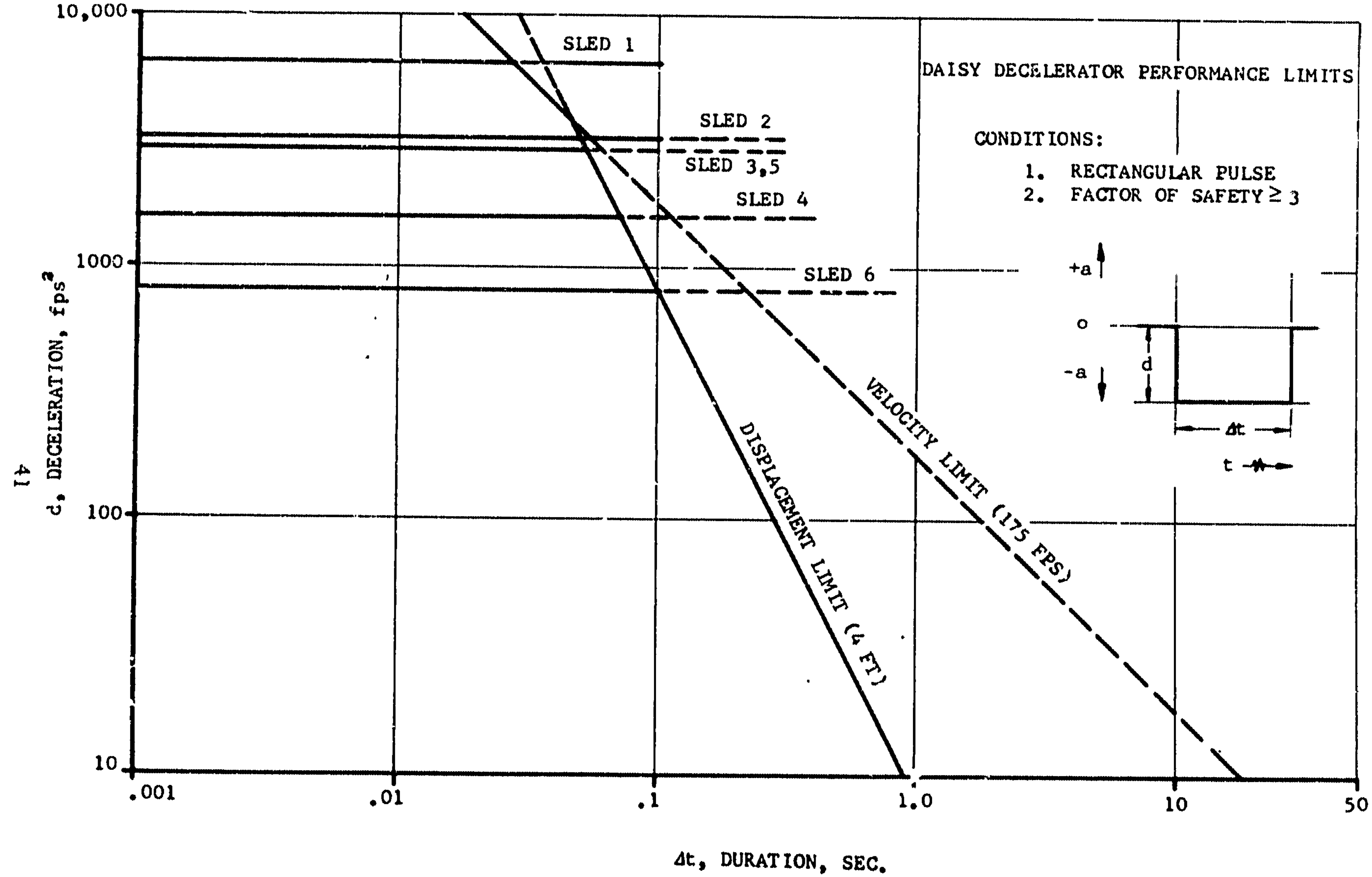


Figure 20. Daisy Decelerator Performance Limits

and the area under the sled lines, represents the combinations of deceleration and duration available. In establishing the curve for sled 2 it was assumed that a 600 lb payload fixture was being tested.

Actual performance under a variety of conditions is shown in Figures 21 through 29.

Figure 21 shows copies of accelerometer tracings taken on sled 1. For this series of tests, no changes in the waterbrake orifice settings were made as the impact velocity was changed from about 20 fps to about 80 fps. This particular pattern was calculated to produce a trapezoidal impact pulse shape with a 30 G deceleration, an onset of 1500 G/sec and an impact velocity of 50 ft/sec. Figure 22 is an overlay of all tests in this series drawn to the same scale. As can be seen, the shape of the impact pulse is fairly well retained and the deceleration level is approximately a function of the square of the impact velocity. The measurements were taken with Statham A6 strain gage accelerometers of the appropriate range, amplifier gain of 100 and low pass filter at 100 Hz, with No. 338 CEC galvanometer in the oscillograph.

Data from two identical, adjacent accelerometers, mounted identically, used on test 2348 are shown in Figure 23. These are shown to demonstrate graphically the importance of proper selection of the filter value; the upper trace was passed through the 100 Hz filter, the lower trace through the 1000 Hz filter. No other significant changes were made.

Similar difficulties can be encountered in other ways. For example, Figure 24 shows three accelerometer data traces taken from adjacent accelerometers on test 2650. All traces represent the same measurement, yet the apparent differences are obvious. As before, the top two traces were obtained using Statham A6 strain gage accelerometers, filtered at 100 Hz and 300 Hz. The bottom trace was obtained from an Endevco 2260 piezoelectric accelerometer, also filtered at 300 Hz. The

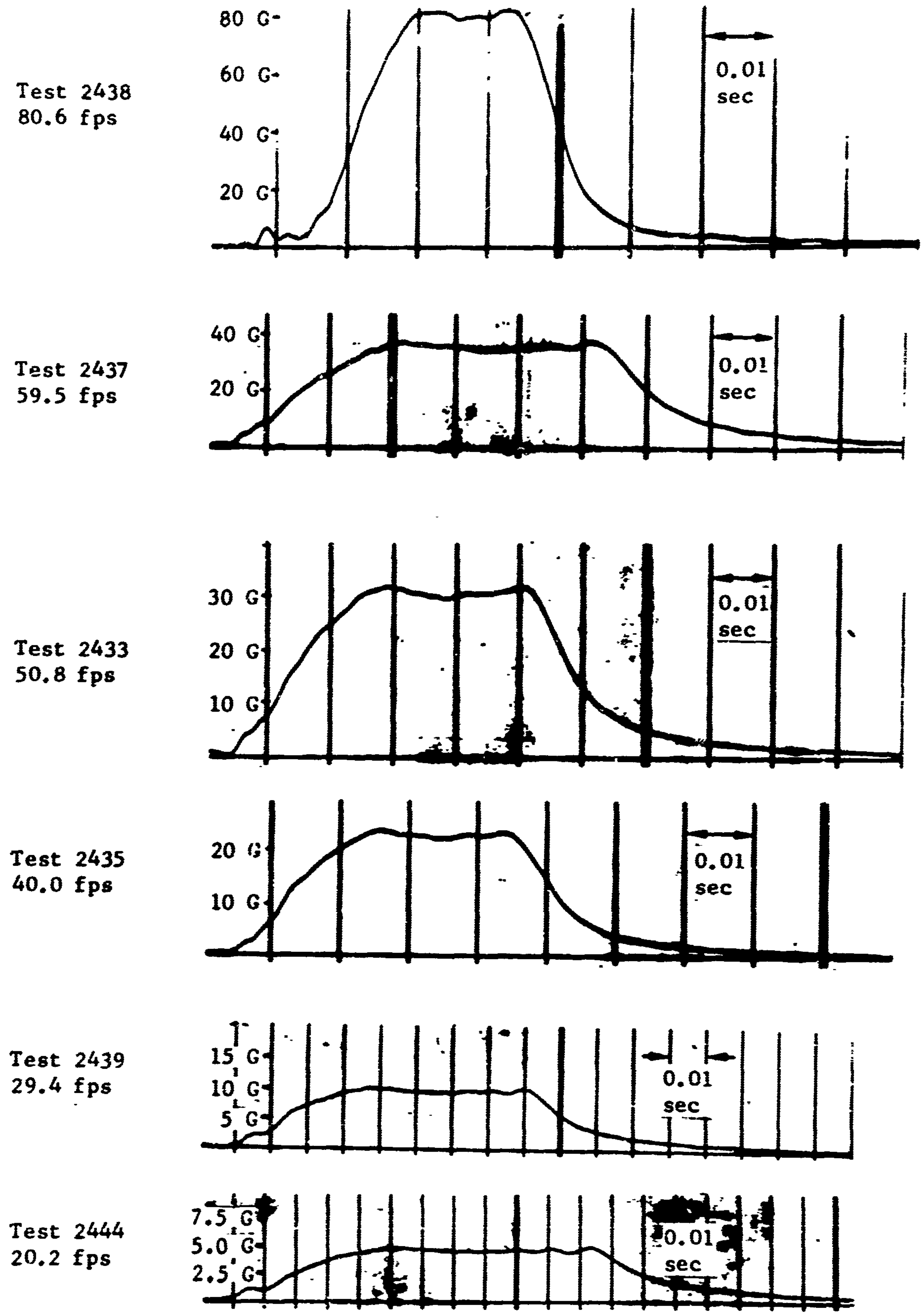


Figure 21. Velocity Variation Tests

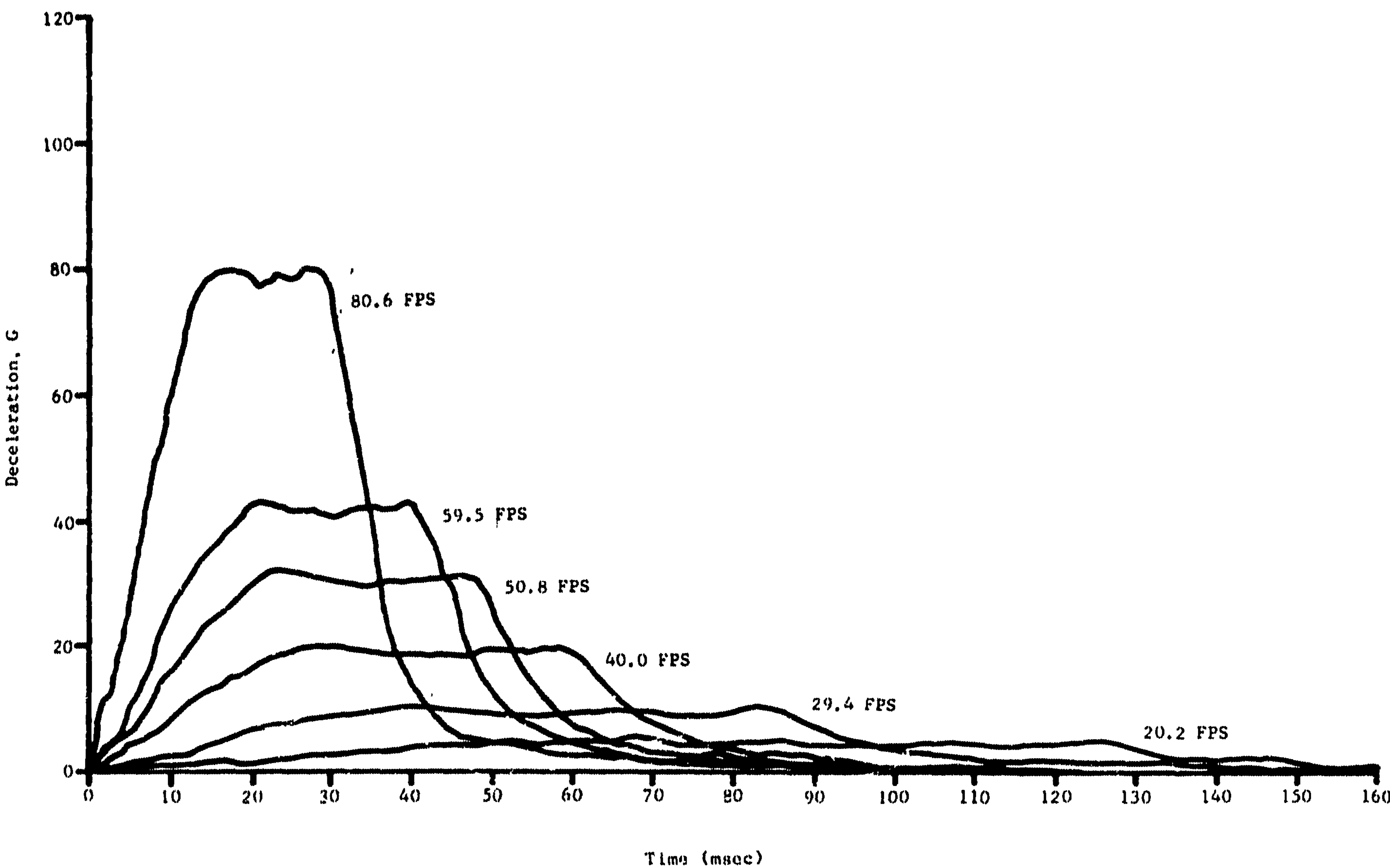
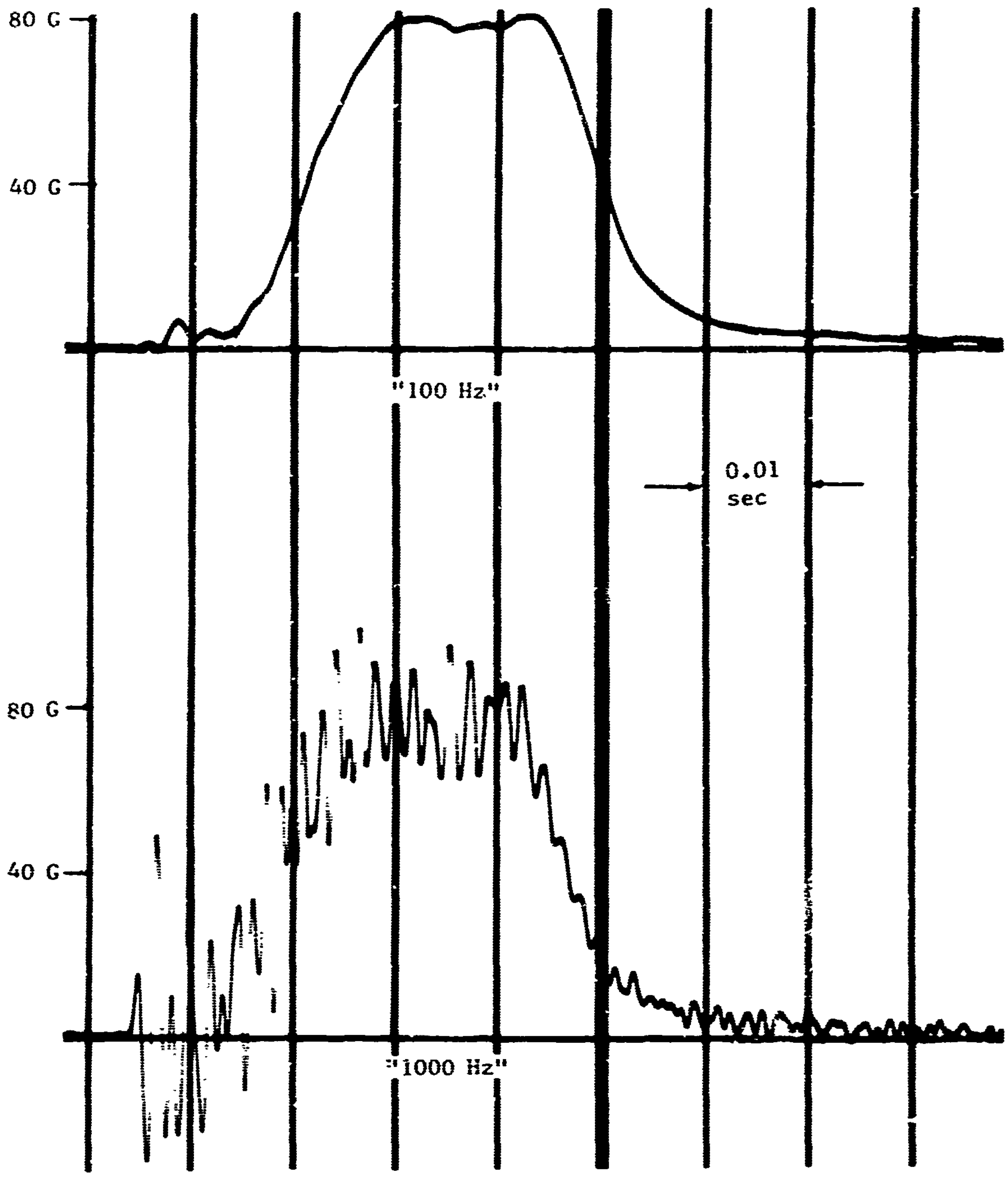


Figure 22. Overlay of all Velocity Variation Tests



Test 2438 - 80.6 ft/sec

Figure 23. Data from Two Identical, Adjacent Accelerometers

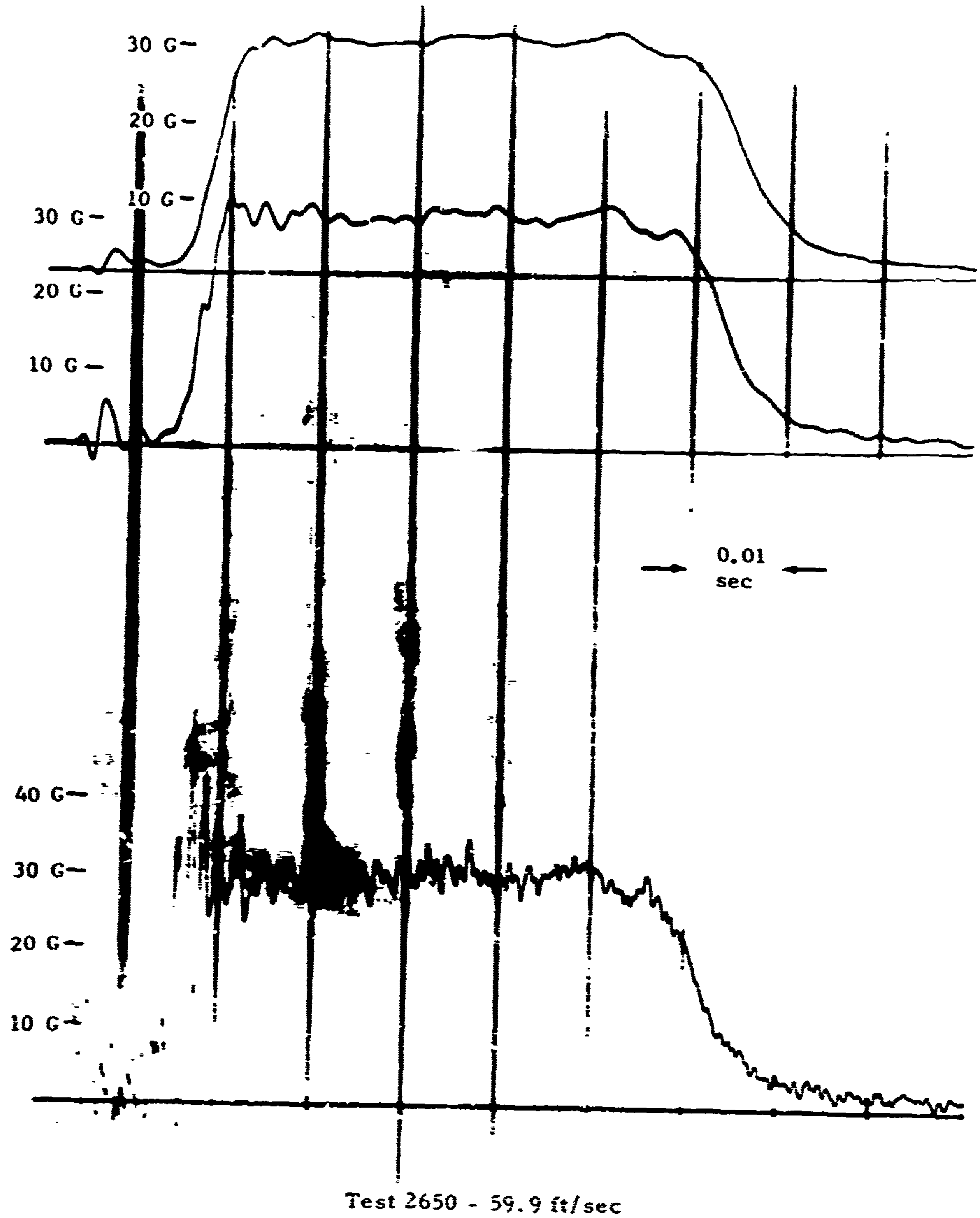


Figure 24. Three Accelerometer Data Traces

importance of the higher frequency components of the lower traces in both figures can be established only after a thorough consideration of the instrumentation, the accelerometer mounting and location, the test item or subject being investigated (and its response characteristics), the purpose of the test data analysis techniques to be used and the test parameters. To eliminate the higher frequency components of a trace by the arbitrary selection of filters or transducers may lose important data, yet the retention of meaningless "hash" on the data trace may well obscure the significant characteristics of the trace, at least to visual inspection. Although it is not expected that each investigator can be expert in the many specialties of engineering and medical sciences applicable to a research program, reasonable care should be exercised in the reporting of the data, particularly in tabular listings of peak G, onset, duration, etc. Figures 23 and 24 show that, even if definitions of these parameters were standardized, the data collection system can affect the data obtained.

For much testing, it is important to know the deviation which may be expected on tests from the many factors which cannot be exactly controlled in a practical sense. These may include variations in wind, lubrication of rails and airgun moving parts, ambient temperature, wear of seals and bearings, airgun energy (small variations in pressure and stored air temperature, for example), etc. To determine this error, a series of 10 tests were made under normal operating conditions at the same test parameters (trapezoidal pulse shape with 30 G plateau, 3000 G/sec onset, and 50 ft/sec impact velocity). The data traces obtained in this series are shown individually in Figure 25, and superimposed in Figure 26. For this small sample, the mean velocity was 50.5 ft/sec, with a standard deviation of about 0.8 ft/sec (1.6%). This resulted in a mean deceleration of about 30.2 G, with a standard deviation of about 1.05 G (3.5 %). These data were obtained with a 50 G Statham A6 accelerometer, amplifier gain of 100, filter set at 100 Hz, and No. 338 CEC galvanometer.

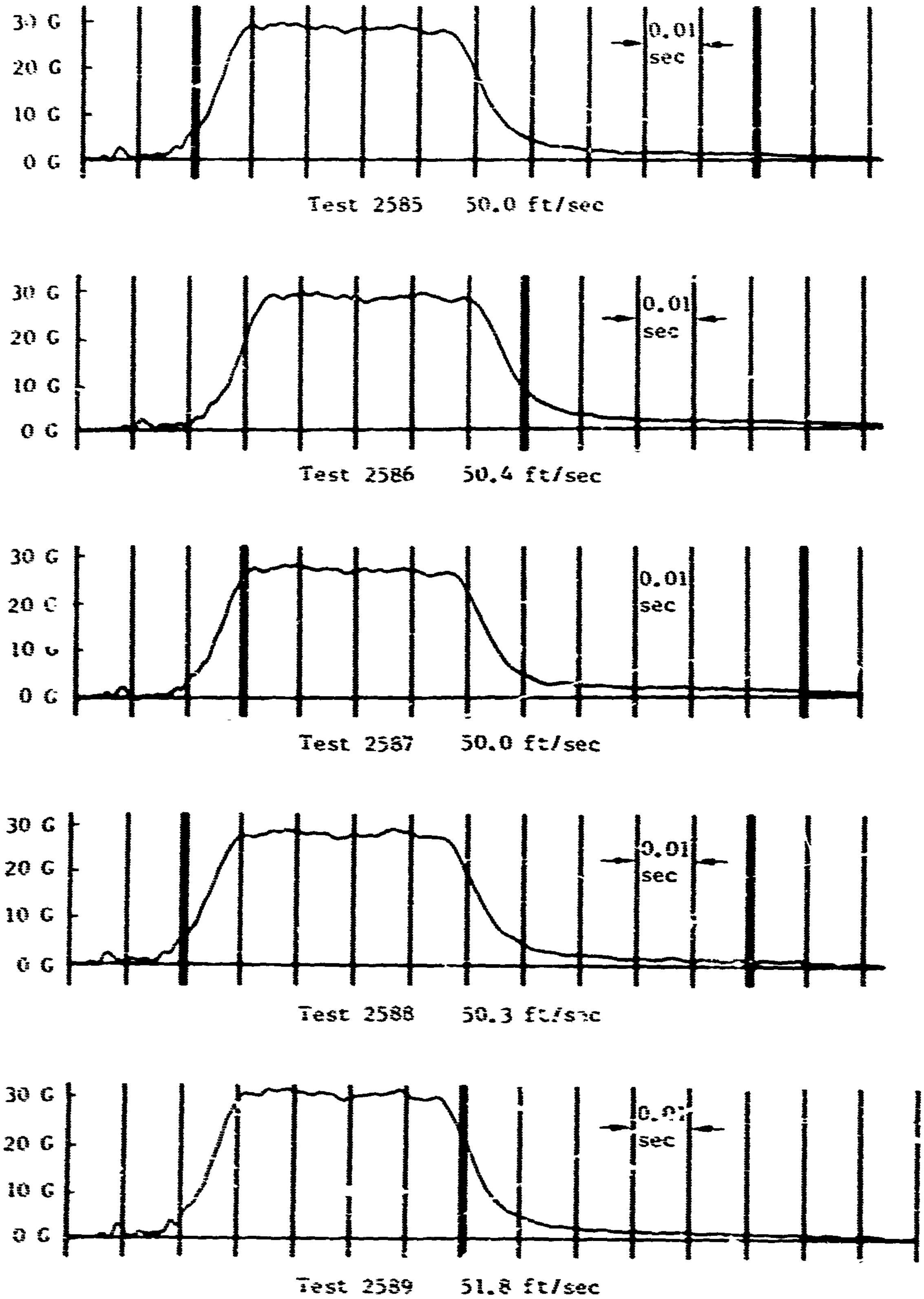
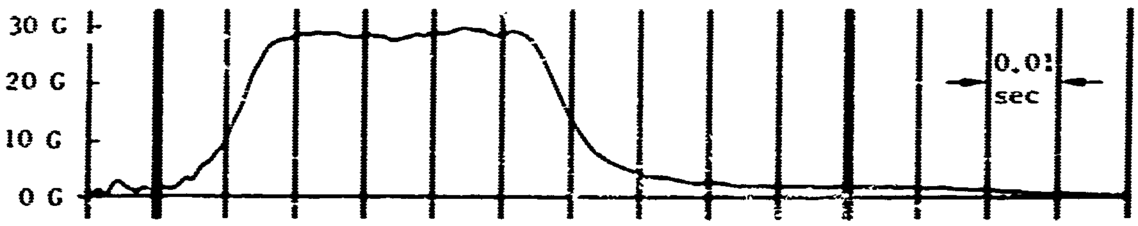
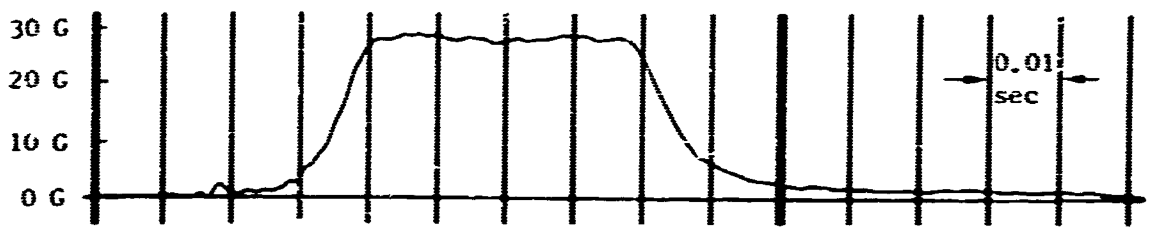


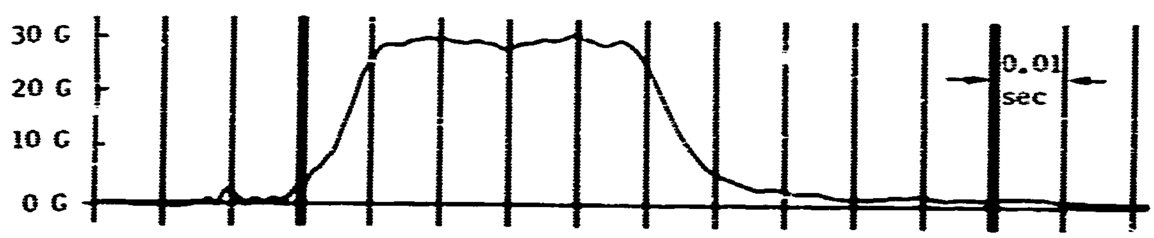
Figure 25. Velocity Repeatability Data



Test 2592 50.0 ft/sec

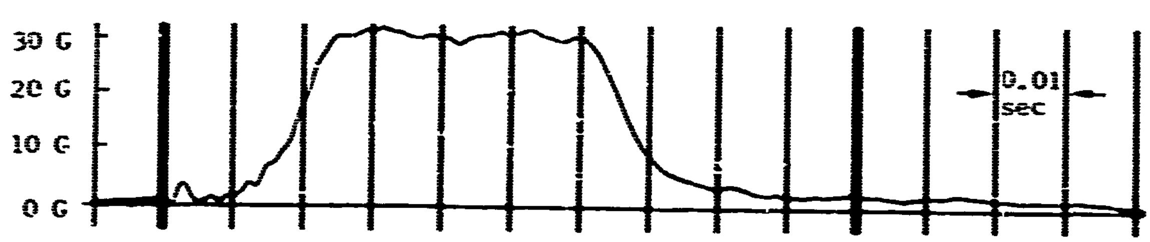


Test 2593 49.7 ft/sec



Test 2594 51.0 ft/sec

Test 2595 50.5 ft/sec



Test 2596 51.0 ft/sec

(Fig. 25 Cont'd)

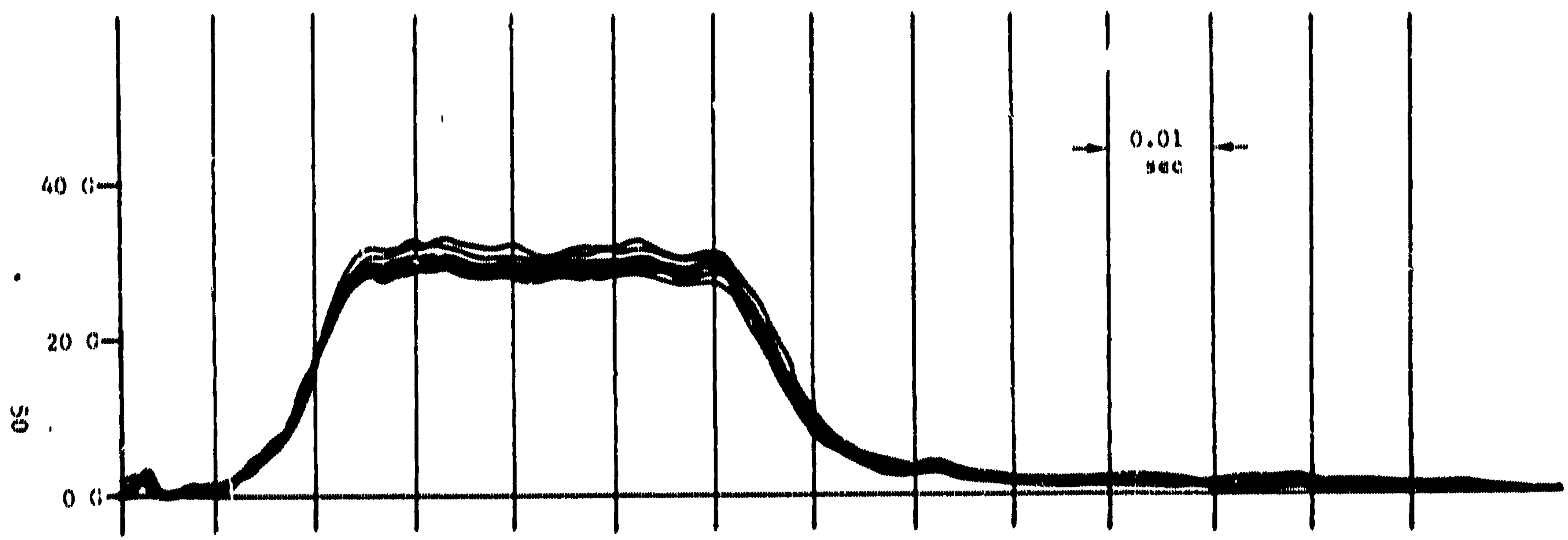


Figure 26. Velocity Repeatability Test Overlay

Figures 27 through 29 are representative of the many impact pulse shapes available through proper selection of the waterbrake orifice plugs. The dashed lines on these figures represent the pulse shape desired, and the curves represent the actual data obtained. Figure 27 shows three test profiles used in a series where it was desired to add a 20 G triangular peak to a 20 G trapezoidal deceleration pulse, and to locate this peak so that it occurred at the end, middle, or beginning of the trapezoid. Figure 28 shows basic triangular (gradual and rapid onset) and half sine impact pulse shapes. All of the data shown was obtained from Statham A6 accelerometers, processed through amplifiers with a gain of 100, filtered at 300 Hz, and recorded using No. 338 CEC galvanometer.

Figure 29 shows two traces taken on tests operating near the maximum performance capability of the facility. Test 2646 was a medium velocity (59.6 ft/sec) 200 G test. The data trace was obtained using a Statham A52 accelerometer, filtered at 100 Hz, and recorded by a No. 338 CEC galvanometer. Test 2642 was a high velocity (151 ft/sec), 130 G test. The data trace was obtained using a Statham A53 accelerometer, filtered at 100 Hz, and recorded using a No. 338 CEC galvanometer.

The data and curves shown in this section are considered representative of what is generally accomplished by the Daisy Decelerator. The infinite variety of impact pulse shapes, which can be generated makes it possible to meet a specific project requirement simply by changes in orifice plug installation or impact velocity, can never be summarized in a report such as this.

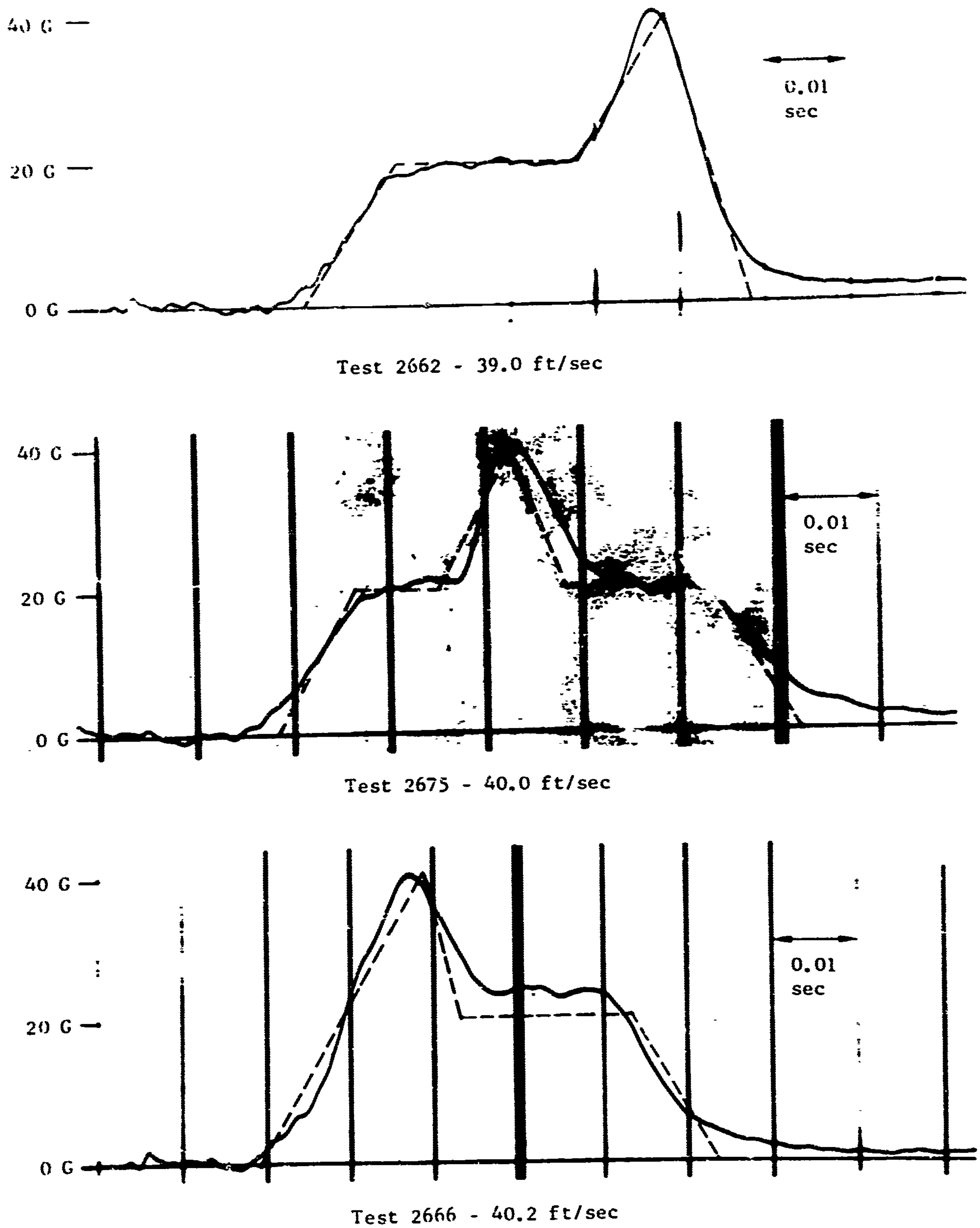
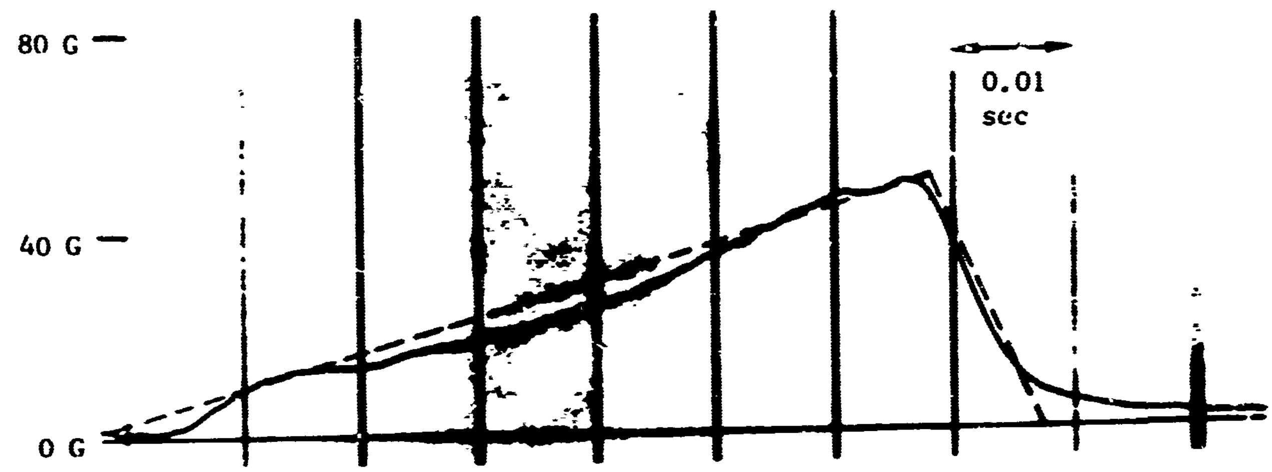
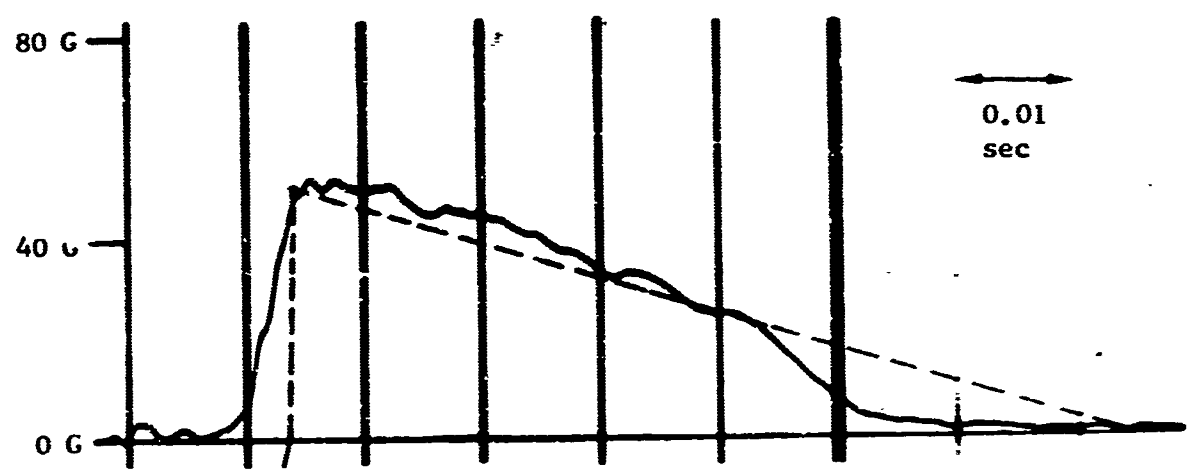


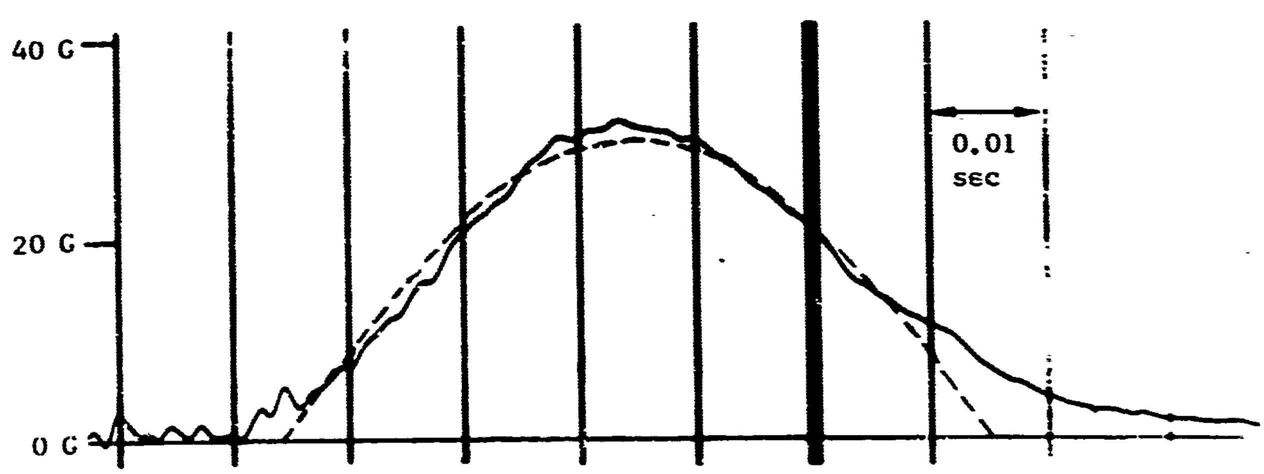
Figure 27. Superimposed Spike Placement Tests



Test 2654 - 65.0 ft/sec

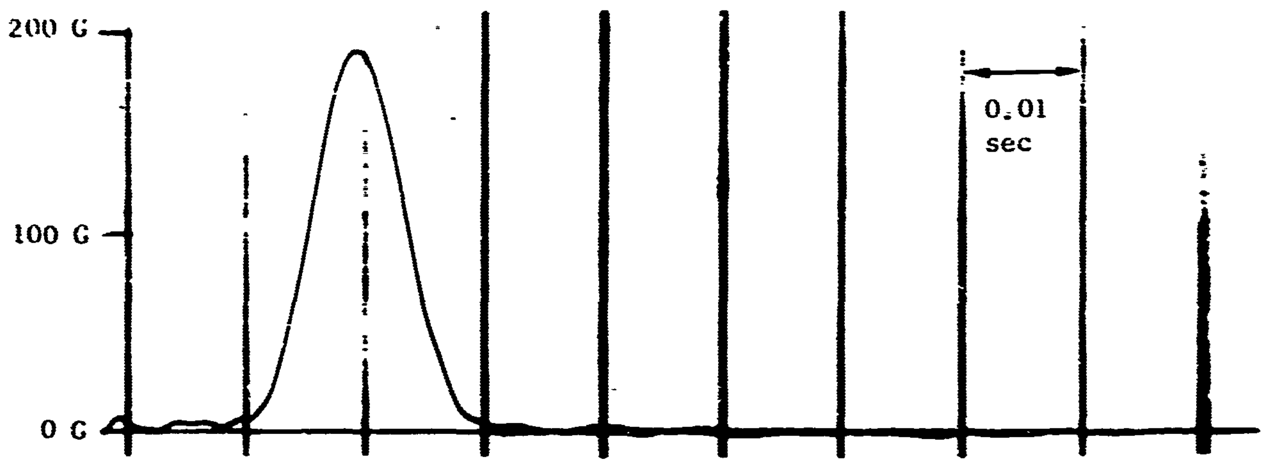


Test 2660 - 59.9 ft/sec

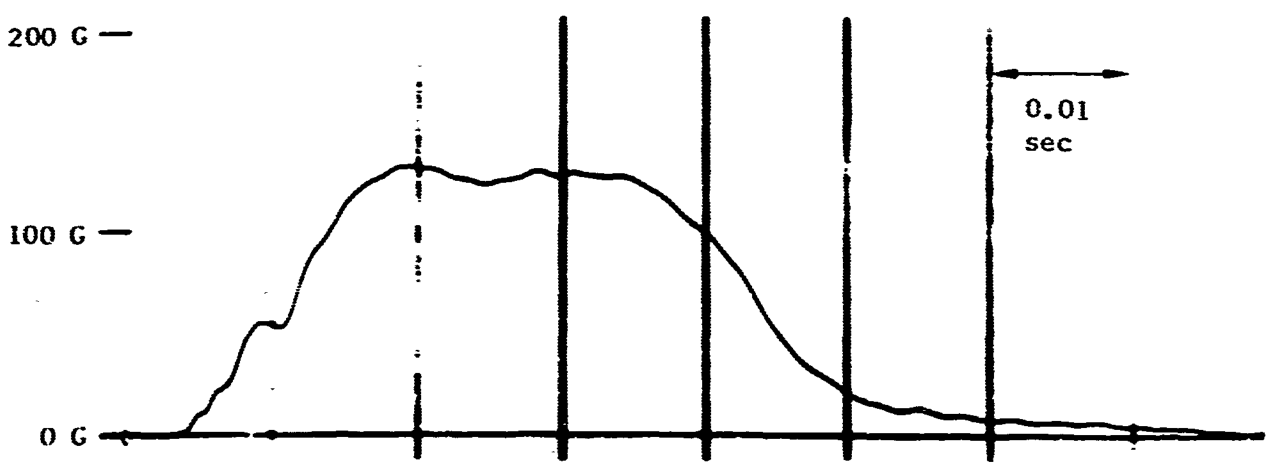


Test 2683 - 43.9 ft/sec

Figure 28. Variations of Impact Pulse



Test 2646 - 59.6 ft/sec



Test 2642 - 151 ft/sec

Figure 29. High-Level Tests

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13. ABSTRACT

The Daisy Decelerator is a sled-track facility used for biodynamic and equipment impact testing at the 657lst Aeromedical Research Laboratory at Holloman AFB, New Mexico. Since its first operational use in 1955, it has been developed to produce an impact force capability of up to 200,000 lbs (equivalent to 200 G for 1000 lb total weight), a maximum impact velocity of 175 ft/sec, and a maximum displacement during impact of 4 feet. Test sleds are available to carry one to three 250 lb test subjects in a variety of orientations relative to the impact force vector. These sleds are capable of accepting other payloads through simple adaptors. Propulsion of the sled is provided by a pneumatic piston device which accelerates the sled to the desired velocity over a distance of 42 feet. The sled is then released to coast into a waterbrake located further down the track. The waterbrake acts on the sled to provide the required impact test pulse. The waterbrake force is controlled by pre-set orifices and can provide a variety of test pulse shapes limited only by the mechanical characteristics of the system. Tests have demonstrated velocity reproduced with a standard deviation of 1.6%, and deceleration reproduced with a standard deviation of 3.5%.

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